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A FLUVIAL GEOMORPHOLOGY PERSPECTIVE ON THE KNOWLEDGE BASE OF THE BRAHMAPUTRA

BY

SANJAY PAHUJA

WORLD BANK, WASHINGTON D.C.

AND

DULAL GOSWAMI,

HEAD OF THE ENVIRONMENTAL SCIENCE DEPARTMENT, GAUHATI UNIVERSITY, ASSAM, INDIA

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1. Introduction

In the pantheon of Indian river deities, the Brahmaputra is the only masculine river god. The legend goes that he came searching for the hand of the Ganges in marriage. The Ganges decided to test his love by turning herself into an old woman. When the Brahmaputra failed to recognize her, she banished him to a distance. Restless, the Brahmaputra kept trying, and managed to finally join the Ganges. This restlessness, however, has stayed with the river, and is consequently enshrined in the mythologies of its people. Along with other traits like generosity, willfulness, and mountain-crushing strength, it completes the character profile of the river god Brahmaputra.

The Brahmaputra river system is one of the largest in the world, and majestic in multiple aspects: in the volumes of water and sediment that it gathers and passes on, the power with which these flows are routed, and the scale of changes that these powerful flows bring upon the landscape. As companion papers in this study point out, the Brahmaputra and other river systems of the Northeast potentially store tremendous wealth for the region, and yet, at the same time, this very same potential turns destructive with fatal regularity every year in the form of floods. While both the potential wealth and the perils of these river systems are well acknowledged, there have not been many significant or successful interventions to address the problem of managing the bounties and the furies of these river gods. One of the reasons is our lack of adequate understanding of the physical processes that govern complicated river systems like the Brahmaputra. While the rivers of the Northeast span a range of typologies, from fast-flowing clear mountain streams to the sediment-laden sealike expanse of the Brahmaputra in Assam, it is the latter that stands out in terms of its enormous and mostly untapped water resource potential, the frequency and severity of its floods, and the unprecedented nature of the river management challenges that it poses.

The objective of this paper is to review and assess our understanding of the Brahmaputra system from the particular perspective of fluvial geomorphology. The paper describes the fluvial geomorphology perspective and presents the rationale for an assessment. The fluvial geomorphology knowledge base is reviewed and evaluated in terms of the relevant data and literature. A framework for assessing the knowledge base is subsequently suggested, followed by a section on the adequacy of the knowledge base, as assessed in the suggested framework. Based on the available information, water and sediment budgets for individual reaches of the system are conducted. The paper concludes with a series of observations and recommendations pertaining to addressing the critical gaps in the fluvial geomorphology knowledge base of the Brahmaputra basin.

2. Fluvial geomorphology

2.1 Definition

A river system is a carrier of water and sediment. The changes in the atmospheric and terrestrial systems for a basin are integrated and manifested in the river system. As the river flows, the dynamics of the exchange between its water and sediment load and the geology and hydrology of the landscape en route creates a complex network of processes, resulting in a given physical form of the river system. Fluvial geomorphology is the interdisciplinary science that attempts to understand these processes and the process-form relationships in river systems. Specifically,

fluvial geomorphology is "the study of sediment sources, fluxes and storage within the river catchment and channel over short, medium and longer timescales and of the resultant channel and floodplain morphology" (Newson and Sear 1993).

In contrast to the traditional engineering approach to river systems, the scope of fluvial geomorphology is to generate understanding at the catchment level with a long-term perspective. The imperative for taking a long-term perspective comes from the nature of its subject: the processes responsible for the physical form of a river system often work slowly, and in many cases a river that appears stable in the short term is actually still responding to the events of the past. The storage of sediment in the catchment and in the channel network and the phases of channel adjustment typically evolve over long timescales. Therefore, even though normal design and operation of river management consider planning horizons of 50 or 100 years, the longer time perspective is fundamental to understanding the functioning of certain river channel processes like planform change and floodplain evolution. Since the transport processes of interest to fluvial geomorphology have long timescales, this also results in expansion of the spatial scale of analysis, and a causal linking of the local to the catchment level of the river system.

The behavior of river systems can be classified on the basis of their equilibrium states, as determined by the balance between three kinds of parameters (Thorne 1997):

- Driving variables: The inputs of water and sediment, generated from upstream channel and catchment processes
- Boundary conditions: The landscape characteristics, for example valley slope and bank materials, decided by past geomorphological processes
- Adjusting variables: The characteristics of the channel form, determined by the interaction of the driving variables with the boundary conditions

Some river systems are in steady state, maintaining the same dimensional form and location features over long time periods. Other river systems exhibit a dynamic equilibrium, outwardly maintaining size and form but progressively changing location over a long time. Threshold behavior has also been observed in some rivers, whereby a small change in either a driving variable or the boundary conditions results in a rapid switch in river characteristics, from one set of dimensions and form to another (Newson 1992). The characteristics of a river's equilibrium state therefore have extensive and significant implications, and an understanding of the equilibrium characteristics requires the long-term and large-scale perspectives developed through fluvial geomorphology assessments.

2.2 Operational relevance

Experience over the last five decades of river management has led to an increasing recognition of the cost, both financial and environmental, of ignoring natural systems, processes, and structures in river management. Numerous river works worldwide have experienced unexpectedly high costs of operation and maintenance, and in some cases outright failure, due to ignorance of or disregard for long-term natural processes, and the evolving paradigm of river management appropriately focuses on retaining as much as possible of the natural hydraulic geometry of self-formed river systems.

It is in this context that the value added by fluvial geomorphology is being noticed by river management agencies. It is now increasingly recognized that by promoting understanding of the complex process-form relationships in river systems, the fluvial geomorphology perspective leads to solutions that are more likely to be sustainable in the long term, as compared to solutions based on conventional engineering practice alone. To address a localized flooding problem, for example, a traditional engineering approach would recommend bolstering the weak points in the flood protection levees. In contrast, a fluvial geomorphological approach would examine the catchment-level processes generating the floods, runoff behavior, storage within the riverbed, and flood routing through the river network, which would lead to examination of such options as creating upstream flood storage areas that could also serve biodiversity protection objectives.

In addition to enhancing sustainability, taking fluvial geomorphology into account also brings direct benefits, in terms of lower overall costs. It has been estimated that a significant proportion of the costs of maintaining and protecting river works can be recovered by using a fluvial geomorphology approach, efficiently targeting solutions based on identifying the causes of erosion and siltation problems that are not commonly considered by conventional engineering practice. Cost savings have been identified in the areas of reduced maintenance frequency, efficient targeting of resources for treatment of erosion and siltation problems, improved design performance (for example in self-cleansing low-flow channels), and designs that protect and maintain the aquatic environment (UK Environment Agency 1998).

At the design stage, a fluvial geomorphology assessment can allow an estimation of the impacts of proposed operations on river form and stability, which is especially valuable in situations involving the threshold behavior of a system under stress conditions, and where it is important to separate the natural and artificially induced changes in the river system. However, not all river systems and not all kinds of river works stand to benefit equally from a fluvial geomorphology assessment. In general, on rivers with appreciable sediment loads, if the proposed interventions can be expected to change the river discharge or sediment load, or if they alter the river channel, floodplain morphology, or the channel boundary materials, then it can be assumed that the fluvial geomorphology will be impacted and therefore some assessment is recommended. Often, problems (or proposed solutions) pertaining to the following issues make a good case for a fluvial geomorphology assessment:

- Sedimentation in riverbed
- Influence of channel adjustment on flood conveyance
- Bank erosion management
- Overbank sedimentation and floodplain evolution
- Deposition of sediments leading to increasing flood frequency and intensity
- River avulsions
- Rehabilitation of riparian wetlands for habitat protection
- Catchment issues like catchment flood management planning
- Environmental impact assessments

Since the early 1990s, applied fluvial geomorphology has become an increasingly significant part of the operational and policy agendas of the river management authorities in many countries (Sear and others 1995; Brookes and Shields 1996), and is seen as vital and necessary for sustainable river system management.

2.3 Framework for assessment

Due to the inherent complexity of fluvial systems and the large spatial and temporal scales of the processes that shape them, a fluvial geomorphology assessment involves a range of data gathering and a variety of analyses at multiple scales. This necessitates a systematic and well-organized approach for conducting the fluvial geomorphology assessment. On large rivers, where high levels of risk and investment are associated with river management, a systematic approach is critical to ensuring that the often limited resources available for an assessment can be effectively deployed to understand the geomorphological issues or impacts related to the reach or intervention under consideration.

Thorne (2002) has proposed a framework and blueprint for geomorphological assessment of large rivers that allows a multilayered and multiscaled comprehensive geomorphological assessment to be conducted through a number of well-defined and semi-independent tasks. This provides both researchers and project managers with a platform for organizing the required knowledge, and for ensuring that resources are adequately allocated to the various components of the study. Figure 1 provides a schematic for the proposed framework, and a description of the component categories is provided in the following sections (based on Thorne 2002).

2.3.1 Performance criteria

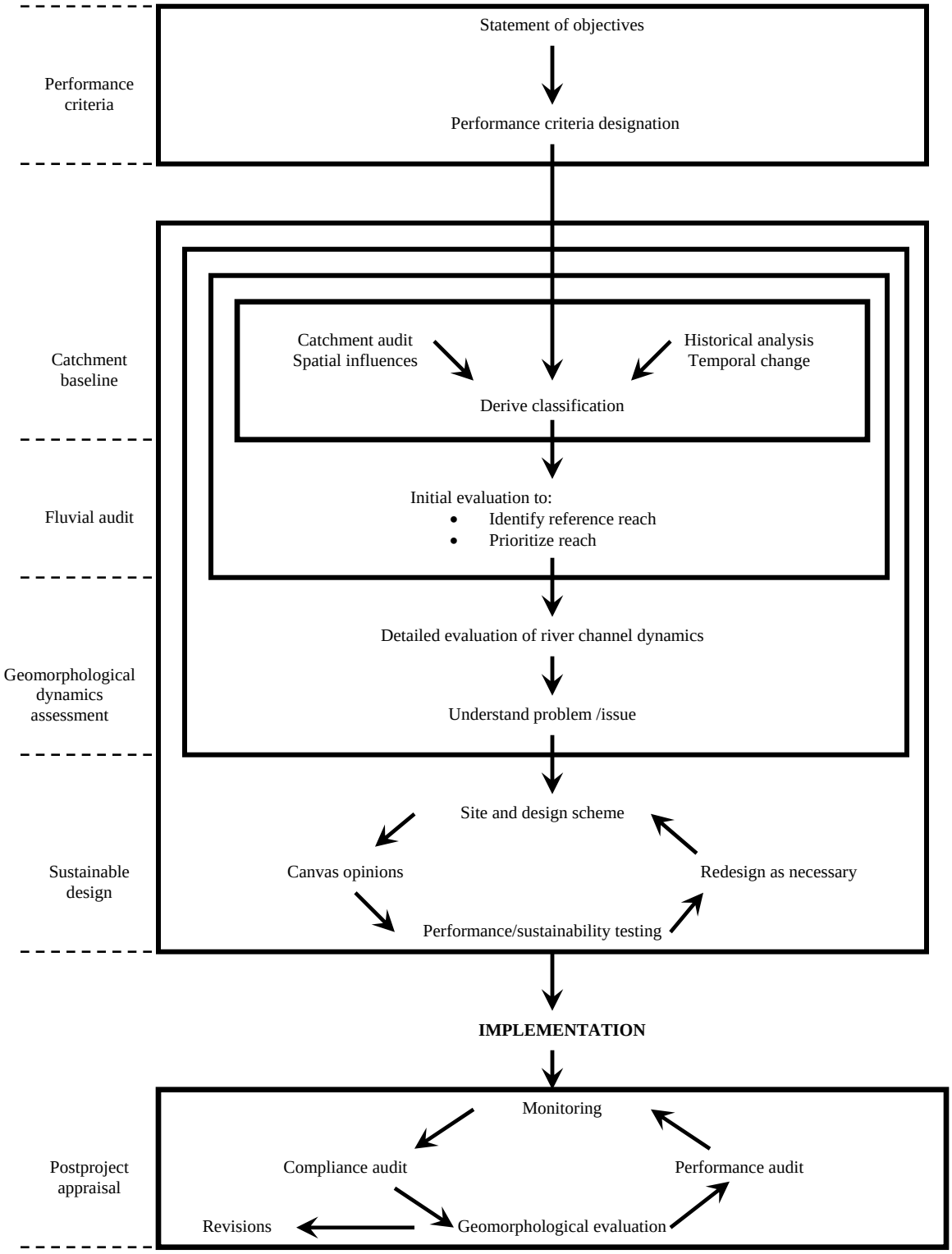
In the context of designing a river project, a geomorphological investigation requires a clear articulation of the geomorphological performance objectives of the proposed intervention. Since most river interventions are multifunctional in nature, and since the functions can often be mutually exclusive to some extent, setting up a priori specific and well-defined criteria of performance allows for geomorphological assessment and design to address these concrete objectives, and for actual performance to be judged against a preestablished objective.

2.3.2 Catchment baseline survey

The catchment baseline survey provides an overview of the past and present physiology, geology, hydrology, land use, and geomorphology of the river basin and its fluvial system. The survey is based on the available documentary information, comprising existing maps, archived information on morphology and ecology, the previous record of engineering interventions, and, when needed, information collected from interviews with relevant management personnel. Limited fieldwork is recommended to supplement the available information. While aerial reconnaissance or satellite imagery can provide a useful overview of the catchment, field visits to carefully selected locations are essential to validating the key characterizing assumptions.

The results of the catchment baseline survey provide details on the catchment characteristics, and a delineation of the nature of the relevant issues and opportunities. In some cases, the survey may provide sufficient basis for the initial geomorphological classification of the channel segments, or reaches, making up the river system. This allows the convenient division of a large system into more manageable study reaches, and identification of key reaches that are likely to be critical from a geomorphological perspective.

Figure 1. Framework for geomorphological assessment of large rivers



Source: Thorne 2002.

2.3.3 Fluvial audit

The objective of the fluvial audit is to relate sediment movement, channel stability, and morphological change at the reach scale to sediment dynamics in the surrounding fluvial system and the wider catchment. In a project-related assessment, the fluvial audit is carried out in the reaches determined by the location of the proposed interventions. Otherwise, the audit is conducted, to the extent permitted by available resources, for those reaches that are identified through the findings of the catchment baseline survey to be strategic for understanding the given river system.

The fluvial audit provides semiquantitative information on the sediment sources, pathways, and characteristics required for understanding the morphological form and state of the river system, and the changes therein, resulting from the past and present adjustments of the fluvial system. By compiling and analyzing the reach-specific information within the suprareach context, the fluvial audit develops an understanding of reach behavior that cannot be developed with exclusive focus on the contemporary conditions in the vicinity of the reach in question. Furthermore, the audit establishes a baseline condition for the reach, from which can be predicted its future autonomous evolution or its likely response to the impacts of the changes that have the potential to destabilize the system.

The fluvial audit approach uses a combination of archival information (on the history of potentially destabilizing phenomena and consequent channel change, as evidenced by photographs, maps, satellite images, and maintenance records of agencies) and field surveys to identify and inventory channel forms and sedimentary features. These are then used by trained geomorphologists to establish the process-form relationships and hence infer the nature of the fluvial processes at work in the study reach.

The outputs of the fluvial audit include a time chart of catchment and river changes that may have had geomorphic impacts, a description of past and contemporary sediment dynamics and channel changes in the study reach, and channel classification maps showing significant morphological features. In project-related assessments, the output of the audit forms the basis for identification of possible solutions for sediment- and instability-related problems. In general, analysis of the fluvial audit would aid geomorphologists in assessing the likely impacts of proposed engineering interventions and in determining their acceptability from a geomorphological viewpoint.

2.3.4 Geomorphic dynamics assessment

The geomorphic dynamics assessment comprises a detailed evaluation of fluvial processes, mechanisms of morphological adjustment, and river channel dynamics. This stage involves significant fieldwork in the study reach, including channel platform mapping, surveys of bed topography and water surface configuration, and measurement of velocity fields in one or more dimensions, suspended and bedload transport rates, lateral erosion rates and processes, bank stratigraphy, bank hydrology, and bank failure mechanisms. These require specialized instrumentation and are labor intensive, and therefore need only be performed at one or a few key sites, which need to be carefully selected based on a thorough understanding of the fluvial system obtained from the findings of the catchment baseline survey and the fluvial audit.

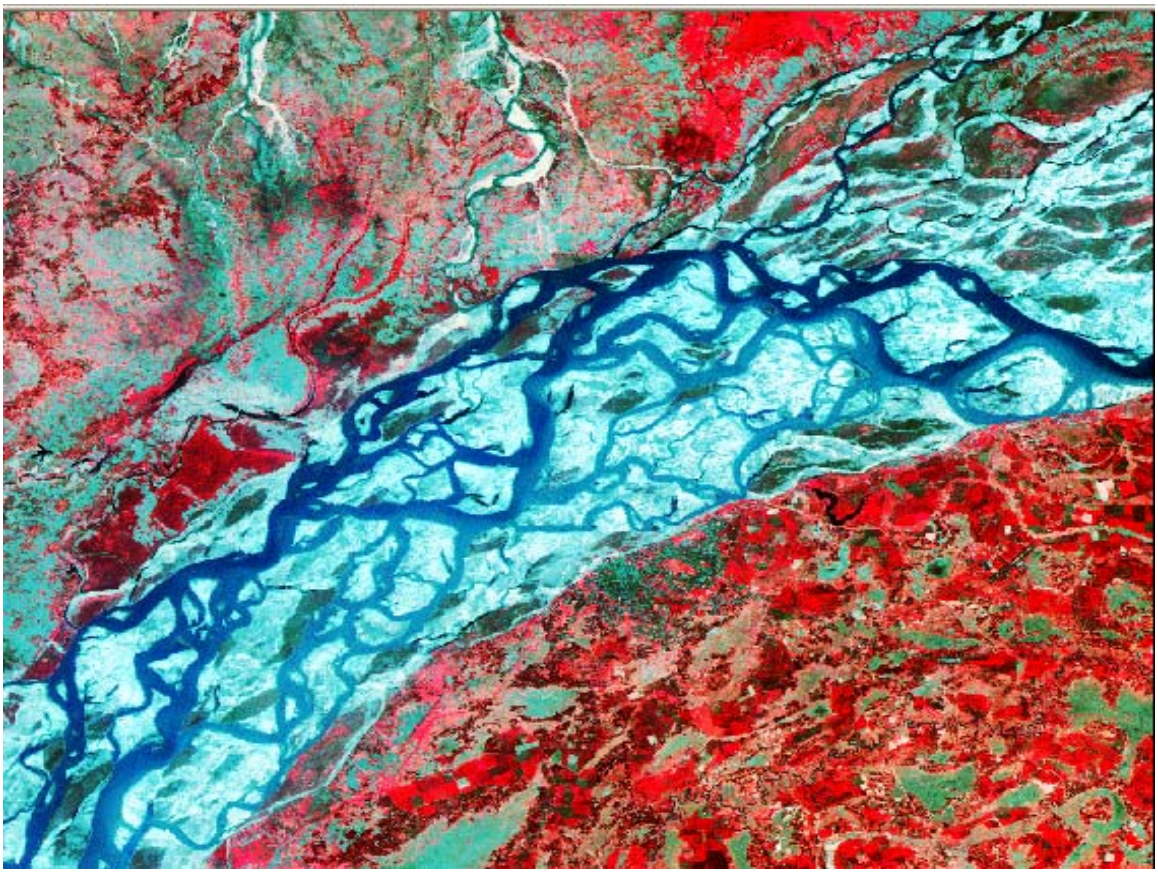
The resource-intensive exercise of the geomorphic dynamics assessment is mostly undertaken in the context of project-specific assessments only, but its design, approach, and utility are all

predicated on the knowledge outputs of the catchment baseline survey and the fluvial audit. The overarching context provided by the survey and the audit is therefore critical to generating correct understanding of river processes and sustainable design of interventions. However, project-specific assessments seldom have the resources, and, more specifically, the time to support the geomorphological assessments for the entire fluvial system. Therefore, the responsibility for conducting systemwide assessments is best placed with the river agencies, as part of their strategic water resource development and management program.

2.4 Relevance of fluvial geomorphology to Brahmaputra system

The Brahmaputra is a large alluvial river with a high degree of braidedness. Figure 2 shows a satellite image of the river at a location near Dibrugarh, demonstrating the complexity of the physical form of the river system and of the governing physical processes responsible for it. The Brahmaputra flows through a seismically active region, which has the effect of causing it to carry one of the highest sediment loads in the world. These factors combine to make this river system unprecedented in terms of the river management challenges it poses to sustainable harnessing of its water resources and effective management of its floods.

Figure 2. The Brahmaputra near Dibrugarh



Source: IRS 1D LISS image.

The Brahmaputra also flows through a region that is home to very delicate ecosystems and rich biodiversity. In addition, any possible trajectory of water resource development has to accommodate the uncertainties associated with the impacts of climate change and economic

development in the region. The challenge of environmentally sustainable development and management of water resources is therefore compounded by the need for a development approach that is functional and resilient over the long term.

The imperatives of physically sound design, sustainable operation, and environmental protection require that river management operations be designed to work with natural processes rather than opposing them. On large rivers like the Brahmaputra, where investments and risks are high, this means that operations have to be designed with an explicit recognition of the project reach as a part of the system continuum, and the river behavior has to be understood in both long-term temporal and catchment-scale spatial contexts.

As an illustrative example, consider the finding that the Brahmaputra river system has not yet reached an equilibrium with regards to sediment loads created by the instability of a major earthquake that shook Assam in 1954. A short-term or site-specific sediment transport analysis, the exercise most likely to carried out in the course of routine project-specific investigations, will fail to reveal this, just as it will fail to reveal which reaches of the river are acting as in-channel sediment storages by undergoing aggradation. A combination of fluvial geomorphological analyses is required to bring this essential fact to light, with attendant benefits to the design of an appropriate river management approach.

Furthermore, an examination of the typical trigger issues (listed in section 2.2) that suggest the applicability and utility of a fluvial geomorphology perspective reveals that the Brahmaputra river system will stand to benefit significantly from investment of resources in understanding its fluvial geomorphology.

3. Fluvial geomorphology knowledge base of the Brahmaputra

The following subsections present an assessment of the available fluvial geomorphology knowledge base for the Brahmaputra basin, including the available datasets and the existing literature pertaining to this subject.

3.1 Inventory of the fluvial geomorphology database

This section attempts to provide an inventory of the database on the fluvial geomorphology of the Brahmaputra river system. The inventory is compiled on the basis of available records in major repository agencies, and is divided into the following four major categories of data: (a) hydrometeorological and sediment discharge data; (b) geospatial data (maps, satellite images, survey reports); (c) geological data; and (d) land use data.

3.1.1 Hydrometeorological and sediment discharge data

The distribution of gauge (G), gauge-discharge (GD), and gauge-silt-discharge (GDS) observation sites located on the Brahmaputra River and their current status are presented in table 1.

There are 62 hydrological observation stations on the main stem of the river in India. Of these, 6 are GDS stations. In addition, there are 53 observation stations (all GDS) on major tributaries of the Brahmaputra. The Central Water Commission is the main coordinating agency for hydrological data collection on the Brahmaputra, and the custodian of all resultant hydrological datasets. Consequently, the data covering river stage, flow discharge, sediment transport,

channel cross-sections, bank configuration and change, and bed and bank materials are available only with the Central Water Commission (through the Brahmaputra Board).

The rain gauge stations maintained by the Indian Meteorological Department (IMD) in the Brahmaputra basin include 336 ordinary gauges and 113 self-recording rain gauges, and these precipitation datasets are available from IMD. The distribution by state of rain gauge stations maintained by IMD in the Northeast is shown in table 2. Given the nature of the terrain and the variability of the pattern of rainfall in the region the network is rather sparse, especially so in the upper catchments of the rivers.

Table 1. Inventory of available hydrological gauge data on the Brahmaputra

Kind of data[a]	Location	Period of record	Repository agency[b]
G	Dibrugarh	1907–1917 & 1933 onwards	CWC/Brahmaputra Board
G	Silghat	1908–1916 & 1955 onwards	CWC/Brahmaputra Board
G	Tezpur	1907–1916 & 1955 onwards	CWC/Brahmaputra Board
G	Guwahati DC court	1908 onwards	CWC/Brahmaputra Board
G	Goalpara	1908 onwards	CWC/Brahmaputra Board
G	Dhuburi bar library	1908 onwards	CWC/Brahmaputra Board
GD	Murkong Selek	1955 onwards	CWC/Brahmaputra Board
G	Neamatighat	1955 onwards	CWC/Brahmaputra Board
GDS	Bechamara	1955 onwards	CWC/Brahmaputra Board
GDS	Bhurbandha	1955 onwards	CWC/Brahmaputra Board
GDS	Pandu	1955 onwards	CWC/Brahmaputra Board
GD	Jogighopa	1955 onwards	CWC/Brahmaputra Board
GDS	Pancharatna	1977 onwards	CWC/Brahmaputra Board
GD	Shigatse (Tibet)	1955–1962	CWC/Brahmaputra Board
GD	Chusul (Tibet)	1955–1962	CWC/Brahmaputra Board
GD	Tsela D'Zong (Tibet)	1955–1962	CWC/Brahmaputra Board
GD	Pasighat	1949–1962 & 1973–1978	CWC/Brahmaputra Board
GDS	Ranghat	1977 onwards	CWC/Brahmaputra Board
GDS	Dihang dam site	1977 onwards	CWC/Brahmaputra Board

a. G = gauge, GD = gauge-discharge, GDS = gauge-silt-discharge.

b. CWC = Central Water Commission.

Table 2. Distribution of IMD rain gauge stations in northeast India

State	No. of stations
Arunachal Pradesh	20
Assam	55
Manipur	6
Meghalaya	7
Mizoram	6
Nagaland	6
Tripura	7

Although not typical of all the rain gauge stations in the Northeast, the patterns of rainfall data availability in selected stations of Assam are presented in table 3.

The state departments of water resources (mainly Assam and Arunachal Pradesh) have collected sets of drill hole data pertaining to various eroding sections along the main stem of the river and many of the tributaries. The analysis of these data can provide useful information regarding the local fluvial geomorphology of the river and the floodplain. However, these datasets are neither regular in spatial distribution nor maintained in a systematized manner, thus limiting their potential value. The lack of sedimentological and soil investigations necessary both within the channel and on its banks for an effective fluvial geomorphology appraisal of the river comprise a major area of weakness in the existing knowledge base.

Table 3. Rainfall data availability in select IMD stations in Assam

Station	Period	No. of years
Dhubri	1881–1991	111
Guwahati	1869 onwards	137
Tezpur	1902 onwards	104
Lakhimpur	1901 onwards	105
Dibrugarh	1902 onwards	104
Pasighat	1657 onwards	49
Imphal	1954 onwards	52
Agartala	1953 onwards	53
Shillong	1867 onwards	139
Cherrapunji	1901 onwards	105
Silchar	1869 onwards	137
Lumding	1901–1991	91
Majbat	1901–1995	95
Kailashankar	1938–1991	53
Haflong	1901–1970	70

3.1.2 Geospatial data

Geospatial data in the form of topographical maps, aerial photography, satellite images, and thematic maps prepared with the help of remote sensing and Geographic Information System (GIS) techniques are available for large parts of the Brahmaputra basin at various spatial and temporal scales. The databases available with government agencies such as the Survey of India, the Department of Space, the Central Water Commission, and state departments of water resources, geology, and mining exclude coverage of certain border areas at certain scales. However, the image sets available from international remote sensing agencies provide full coverage of the basin. In addition, cloud-penetrating terrain image sets are now also available for the entire basin, enabling crucial monsoon and postmonsoon flood mappings.

In terms of data pertaining to river channel evolution, the Central Water Commission maintains a database of channel cross-sections at more than 65 locations on the Brahmaputra (at intervals

of 15' on East longitude), providing for detailed measurements of river channel form and location.

3.1.3 Geological data

The Geological Survey of India has conducted and published geological assessments covering the whole basin. The basin has also been studied fairly widely by the international geological research community. In addition, various state agencies are repositories of detailed geological information pertaining to specific subregional investigations. As a result, the geological landscape and its historical evolution are fairly well understood at the basin scale. However, from the fluvial geomorphology perspective, the databases are neither adequately collated nor cataloged.

3.1.4 Land use data

Data pertaining to current and historical land use in the Brahmaputra basin are collected and maintained by state departments with varying degrees of consistency and systematization. The data pertain mostly to urban and agricultural land uses, and have poor reliability for areas under forest cover or under traditional tribal land use practices. Thus, the datasets are inadequate in their coverage, and are of poor quality from the perspective of catchment analysis requirements. Furthermore, the available datasets are neither adequately collated nor cataloged.

3.2 Assessment of the available fluvial geomorphology database

Thorne's (2002) framework for fluvial geomorphological studies of large alluvial rivers provides a comprehensive and structured approach to analysis of fluvial processes and associated landforms in these vast and dynamic river systems. Based on the presentation of the framework in section 2.3, the available database has been assessed for adequacy and appropriateness for various fluvial geomorphology assessments presented below. The assessment is conducted on the basis of the status of availability of known data from official sources.

3.2.1 Catchment baseline survey

The status of available data is as follows:

- **Topographic mapping.** The input data required for the analysis, such as topographical maps, are available in the country with both central and state government agencies. However, the data available from the central agencies, such as the Survey of India and the Department of Space, are mostly primary and generally of better quality. These data are adequately available.
- **Geological mapping.** The Geological Survey of India and several other central and state governmental departments and agencies have adequate coverage of the study area with good quality data. However, compilation work is required for systematizing the available information.
- **Soil mapping.** Soil maps and data are available with agencies like the National Bureau of Soil Survey, the Department of Agriculture, and the Central Water and Power Commission. However, for the hilly regions and the sensitive border regions, there may be difficulty in getting maps of the desirable scale. The National Remote Sensing Agency (Department of Space) has also prepared some soil maps based on remote sensing data, but these are of lower resolution and have not been extensively ground-truthed.

- **Geomorphic mapping.** The Geological Survey of India, the Department of Space, state departments of agriculture, and remote sensing application centers have prepared geomorphological maps of the region. However, detailed mapping for the region needs to be based on already available satellite and ground-based data.
- **Land use and settlement mapping.** Land use and land cover mapping has been carried out for the region by the Department of Space, NBBS, and NATMO. While these data are of adequate coverage, they lack ground verification in certain areas under forest cover or under traditional land use practices in remote regions.
- **Long-term evolution and change in the catchment and drainage system.** Adequate coverage of satellite data is available with the Department of Space. Agencies like GSU, the Central Water Commission, and relevant state departments also possess some amount of historical data. However, these have not been utilized towards a focused analysis of long-term change in the system. Thematic spatial data products at the appropriate scales have not been prepared.
- **Initial subdivision and classification of channel systems.** Satellite data and topographical sheets are available with central agencies like the Department of Space and the Central Water Commission (Brahmaputra Board). However, the analysis needs to be done using the identified methodology.

3.2.2 Fluvial audit

The status of available data is as follows:

- **Determination of dominant discharge and range of effective flows. D**ata are available with the Central Water Commission (Brahmaputra Board). Some analysis, such as preparation of sediment rating and flow duration curves, may have been conducted by the Brahmaputra Board while preparing the Brahmaputra basin master plans and various other reports. However, these are not available in the public domain and are therefore not reviewed. There are no sediment concentration or sediment transport data from depth-integrated sediment samplers, and this is a serious constraint in conducting the required analyses.
- **Specific gauge analysis.** The required data are available with the Central Water Commission. However, some additional analyses need to be done on topics such as fluvial analysis of bed forms, bed level changes, and flow resistance.
- **Downstream hydraulic geometry analysis of main channel cross-sections.** The required input data exist with the Brahmaputra Board and the state Water Resources Department. Some additional data on specific areas may be needed.
- **At-a-station hydraulic analysis of geometry and pattern changes with changing stage.** Satellite images and aerial photographs of river cross-sections are available with the relevant central government agencies, such as the Brahmaputra Board and the Department of Space. Some additional data may be needed in regard to cross-sections and flow lines for dominant discharge.
- **Long-profile analysis of thalweg, bar top, bank top and water surface profiles.** The Central Water Commission, the Brahmaputra Board, and the Indian Space Research

Organization have collected data of a general nature. However, specific information on hydrographic surveys for thalweg, bank top, and water surface profiles does not exist.

- **River planform analysis.** Satellite maps, aerial photographs, and current maps are adequately available with the Central Water Commission, the Department of Space, and relevant state government departments. However, shifting of thalweg and wandering of channel and its geometry need to be surveyed more precisely using remote sensing and GPS technologies.
- **Braiding intensity analysis.** Adequate data are available with the Department of Space, the Survey of India, and several state agencies. However, there is a requirement for data at more cross-sections in eroding reaches such as those at Dibrugarh, Neamati, Moriahola, and Palasbari.
- **Semiquantitative sediment analysis.** Data are available with the Central Water Commission (Brahmaputra Board), the Department of Space, and other government agencies, but the measurement approaches do not use accurate modern technologies. Sediment load data measured with depth-integrating samplers are not available.

3.2.3 Geomorphic dynamics assessment

The status of available data is as follows:

- **Braiding processes and dynamics.** Data on bed topography and bedload transport are not available.
- **Meandering (bendway morphology analysis).** Field measurements of bed topography, profiles, and bedload transport are nonexistent.
- **Meandering (velocity field analysis).** The database on field measurements of velocity fields and scour pattern depths is not adequate. This seriously hampers efforts to conduct empirical studies and model testing.
- **Meandering (migration and bend-shifting analysis).** The database availability is not known.
- **Recent bankline changes and width adjustments.** The required data are available with agencies such as the Central Water Commission and the Department of Space.
- **Field reconnaissance of bank stability and failure.** There are significant gaps in the availability of spatial data.
- **Bank stability analyses using slope stability models.** There is a considerable data gap in this area. Bank profile surveys, stability analysis, and stratigraphic studies are needed on a broader scale. Measurements on eroding sections need to be emphasized.
- **Comparison of bank and bar sediment size distributions.** Data are available for a few specific sites. Datasets are extremely sparse.

3.3 Fluvial geomorphology literature review of the Brahmaputra system

The literature review accessed the scientific documents available on the subject in the following four categories: (a) journals and monographs; (b) reports (published by government and

nongovernment organizations); (c) proceedings of conferences, seminars, and workshops; and (d) theses and dissertations (Ph.D., M.Phil., and M.E.). The literature is classified into a number of relevant fluvial-geomorphological subthemes, namely flow characteristics, sediment characteristics, bank erosion, bed level changes (aggradation and degradation), channel planforms and behavior, alluvial flow modeling, fluvial morphology, flood studies and geomorphology, and miscellaneous (for example water quality, meteorological data, water resource development).

More than 300 documents have been assessed in terms of their quality and relevance, and of these 205 are included in the literature review (appendix A). In addition to the classification based on fluvial-geomorphological subthemes, the literature compiled in this review has also been categorized with regards to its relevance to the main stem of the river (table 4a), to the tributaries (table 4b), or to the miscellaneous floodplain features (table 4c). A rating scheme is used to identify the documents that are considered significantly useful: these are indicated with a (+) sign in the tables. The serial numbers of the documents in the tables are identical to those in the original list presented in appendix A.

Table 4a. Literature related to the main stem of the Brahmaputra River

Themes \ Sources	Journal publications	Reports	Seminar/conference presentations	University degree theses
1. Sediment	141+, 142+, 144 , 176+, 178+, 179+, 190+		187+	3, 20+
2. Flow/water balance			86, 192+, 193+	16+, 26+
3. Bank erosion	168+	69+, 70+, 71+, 72+, 96+, 97+, 175+		4+, 22+, 37+, 57, 62+
4. Bed level changes				13
5. Channel form/migration/bar	116, 177+	65+, 115+, 123+, 138+, 159+	194+, 195+	28+, 63, 198, 199+, 200, 202
6. Wetland				
7. Fluvial landform				
8. Modeling			78+, 180+, 196	40+, 52+, 58+, 188+, 189+, 201+
9. Fluvial morphology/soil	164, 172	112+, 113+, 114+, 118+, 147+, 156+, 205+	151, 152+, 191+	64+, 204
10. Flood & flood management	84, 121, 149+, 169, 170, 181+	127+, 128, 132+, 135+, 136+, 158+, 171, 174+, 186+	79+, 80, 82, 83, 85, 139+	17, 45+, 77, 150+, 203
11. Morphology				
12. Watershed				
13 Miscellaneous (meteorology, water quality, water resource development)	140+, 162	99+	197+	10+, 182+

Table 4b. Literature related to the tributaries of the Brahmaputra River

Themes \ Sources	Journal publications	Reports	Seminar/conference Presentations	University degree theses
1. Sediment		89+, 145	91+, 119, 143	21+, 23+, 54, 117+
2. Flow/water balance	134+		76	2, 41, 42, 49+, 55, 184+
3. Bank erosion				19+, 183+
4. Bed level changes				
5. Channel form/migration/bar	90+	161		30
6. Wetland		95+, 106+	107+, 108, 109, 110, 111+	1+
7.Land form/land use	129, 130			27, 60+
8. Modeling			81+	39+, 59+
9. Fluvial morphology/soil	87, 148, 163, 165	88+, 98+, 104, 122+, 137+, 157, 160+	92+, 93, 94	5+, 18+, 24, 32, 33, 43, 44, 67, 101+, 102+, 103, 120+, 166+, 185+
10. Flood & flood management	153	124+, 125, 131, 146, 154+, 155, 167+	126	11, 12, 14, 15, 29, 38, 46+, 47+, 48+, 51, 56, 61+, 100
12. Watershed				25, 50, 53
13. Miscellaneous (meteorology, water quality, water resource development)				36

Table 4c. Literature related to miscellaneous floodplain features of the Brahmaputra River

Sources / Themes	Journal publications	Reports	Seminar/conference presentations	University degree theses
1. Sediment				
2. Flow/water balance				
3. Bank erosion				
4. Bed level changes				
5. Channel form/migration/bar				
6. Wetland				31
7.Land form/land use				
8. Modeling				
9. Fluvial geomorphology/soil	173	66+		
10. Flood & flood management		73, 68+		
12. Watershed				
13. Miscellaneous (meteorology, water quality, water resource development)	105+	74, 75, 133+		6, 7, 8, 9, 34, 35

4. Estimation of water and sediment budgets for individual reaches

Estimations of water and sediment budgets for individual reaches of a river are useful procedures in understanding the dynamics of movement, storage, or removal of water and sediment in systems. These estimates provide a framework for scientific analysis and a basis for policy decision and management. In the case of a vast and dynamic alluvial river like the Brahmaputra, which exhibits a high variability in flow and sediment yield, changing boundary conditions of the channel, complex river morphology, and recurrent seismic instability in the basin region, the uncertainties involved in the estimation are significantly high. Yet, the studies conducted so far in this regard indicate useful results and prospects for further development.

4.1 Gross water budgets

For the estimation of runoff from contributing tributary basins in respect of a given reach of river, water yield at or near the tributary outfall based on observed discharge provides a useful parameter. For the tributaries of the Brahmaputra system, water yield data based on the discharge observations for the 1970–1980 period are given in table 5. Water balance equations are traditionally used for estimation of runoff from watersheds. These are primarily based on available meteorological records. These estimates also help in budgeting water in individual reaches of a river.

Table 5. Water and sediment yields of selected tributaries of the Brahmaputra

River	Drainage area (km^2)[a]	Water yield ($l^{-1}km^{-2}$)[a]	Sediment yield ($m\ t\ km^{-2}yr^{-1}$)[a]
Brahmaputra at:			
Tsela D'Zang (China)	191,222	10.5	100
Pasighat (India)	244,700	23.1	340
Pandu (India)	500,000	30.6	804
Pancharatna (India)	532,000	50.9	964
Bahadurabad (Bangladesh)	580,000	33.1	1,128
Dibang	12,120	10.6	3,765
Lohit	22,077	70.9	1,960
Subansiri	27,400	75.6	959
Jia Bharali	11,300	85.8	4,721
Puthimari	1,787	40.3	2,887
Pagladia	383	108.7	1,887
Manas	36,300	23.2	1,581
Buridihing	4,923	78.8	1,129
Desang	3,950	38.2	622
Dhansiri	10,240	18.4	379
Kopili	13,556	18.2	230

a. km = kilometers, l = liters, m t = metric tons.

Source: Goswami 1985.

A typical water balance equation for use in accounting flow in a river reach of the Brahmaputra may be of the type:

$$Q_d \Delta t = Q_u \Delta t + Q_g \Delta t - E \Delta t \pm \Delta (SRB) + Q_t \Delta t - Q_o \Delta t$$

where

Q_d = flow rate at the downstream end

Q_u = flow rate at the upstream end

Q_g = groundwater contribution

Q_t = flow rates of tributaries

E = evaporation rates

SRB = change in bank storage

Q_o = flow rate diverted from the river

Based on limited data available for the period 1975–1990, a gross water balance for the Brahmaputra at Pandu has been calculated, as given in table 6.

Table 6. Water balance of the Brahmaputra River at Pandu

Drainage area (km^2)	Rainfall (mm)	Runoff (mm)	Evapotranspiration (mm)	Yield ($l/s/km^2$)	Discharge (m^3/s)	Runoff coefficient
500,000	2,300	1,251	1,230	39.7	19,830	0.54

The task of estimating runoff from several subbasins of the Brahmaputra is quite challenging, given that the basin areas are very large and complex and the existing database is sketchy. A multivariate regression model using remote sensing data on basin parameters and coupled with conventional data on rainfall, discharge, and relief has therefore been developed for the Brahmaputra. The regression model developed based on these hybrid data (Goswami 2005) estimates the runoff as:

$$Q = 6403.12 - 3.27 X_1 - 324.58 X_2 + 13.9 \times 10^6 X_3 + 348.11 X_4 + 371.11 X_5 + 66.68 X_6$$

where

Q = mean annual flow (m^3s^{-1})

X_1 = basin rainfall (mm)

X_2 = drainage area (km^2)

X_3 = relief/length ratio

X_4 = basin forest cover (km^2)

X_5 = basin agricrop area (km^2)

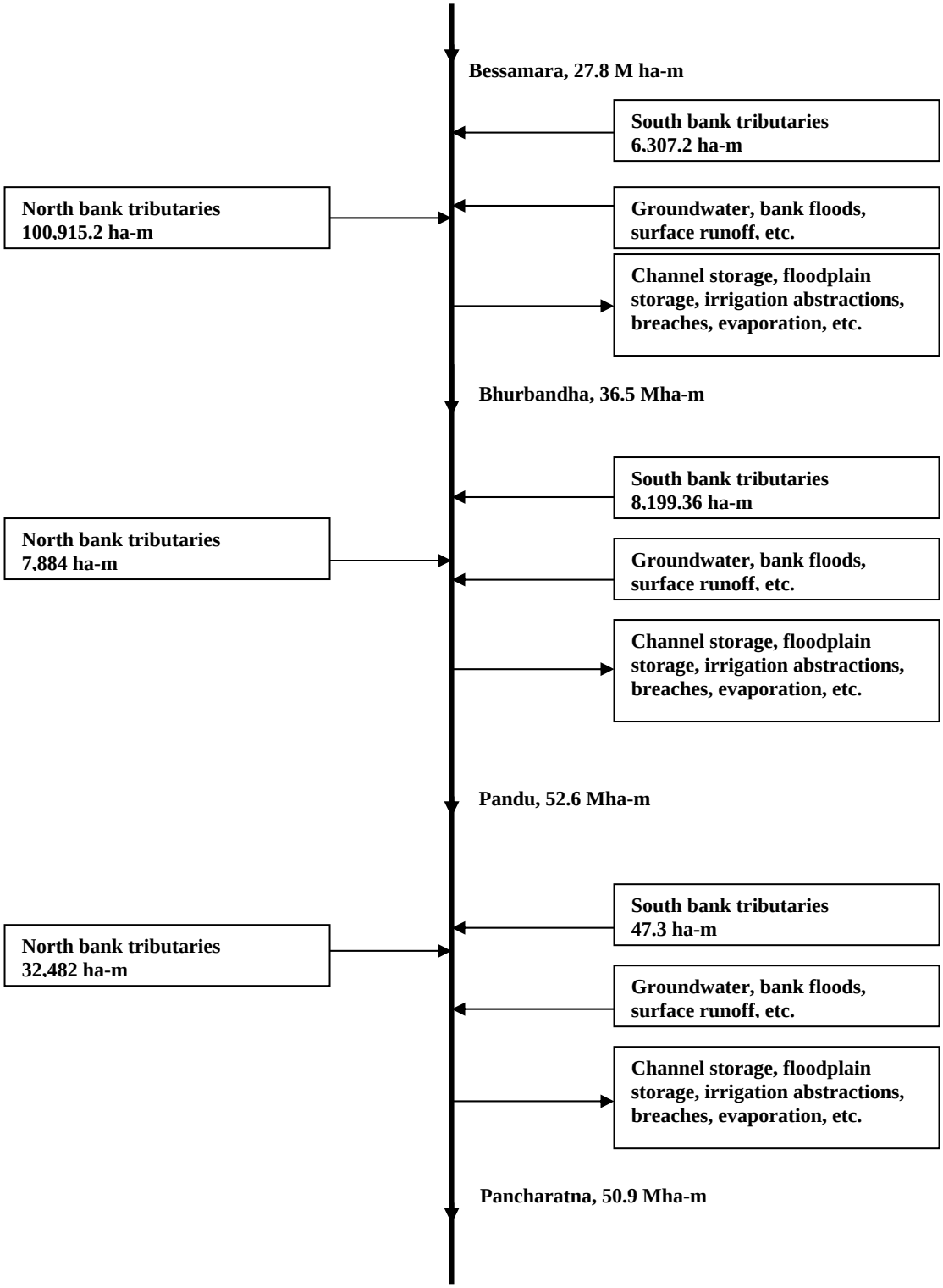
X_6 = areas other than the forest and crop cover (km^2)

The standard error of the equation has been estimated at 10 percent. Similar hybrid approaches based on incorporating remote sensing data to the extent available can be

quite useful for effectively estimating the patterns of runoff contribution from the different watersheds of the Brahmaputra basin.

A water budget for mean annual flow for the three reaches of the Brahmaputra in Assam – Bessamara-Bhurbandha, Bhurbhanda-Pandu, and Pandu-Pancharatna – is prepared here based on limited available data for the period 1971–1990. While some of the main stem data used here are taken from available government documents, the data pertaining to various tributaries are partly derived from available official records and supplemented with estimates made by the second author from several indirect sources and personal judgment. The inflow received in the reaches from groundwater, bank flows, surface runoff, and direct precipitation could not be estimated in the absence of any available data. The same is true for channel storage, floodplain storage, abstractions for irrigation, and losses through evaporation and breaching of embankments. However, these contributions and losses are expected to be low enough not to severely affect the budgeting made here based on the main stream and tributary flows. The schematic diagram showing the accounting of water at selected reaches on a gross level is presented in figure 3. The water budget indicates that the main stem gains net flows in the Bessamara-Bhurbandha and Bhurbhanda-Pandu reaches, while there is a net loss in the reach between Pandu and Pancharatna. The loss in the Pandu-Pancharatna reach may be attributed mainly to floodplain storage, breaches, and wetland storage, as the adjoining floodplains on both sides of the river are acutely flood prone and there are large wetlands and other natural depressions.

Figure 3. Flow budget for the Brahmaputra River reaches in Assam



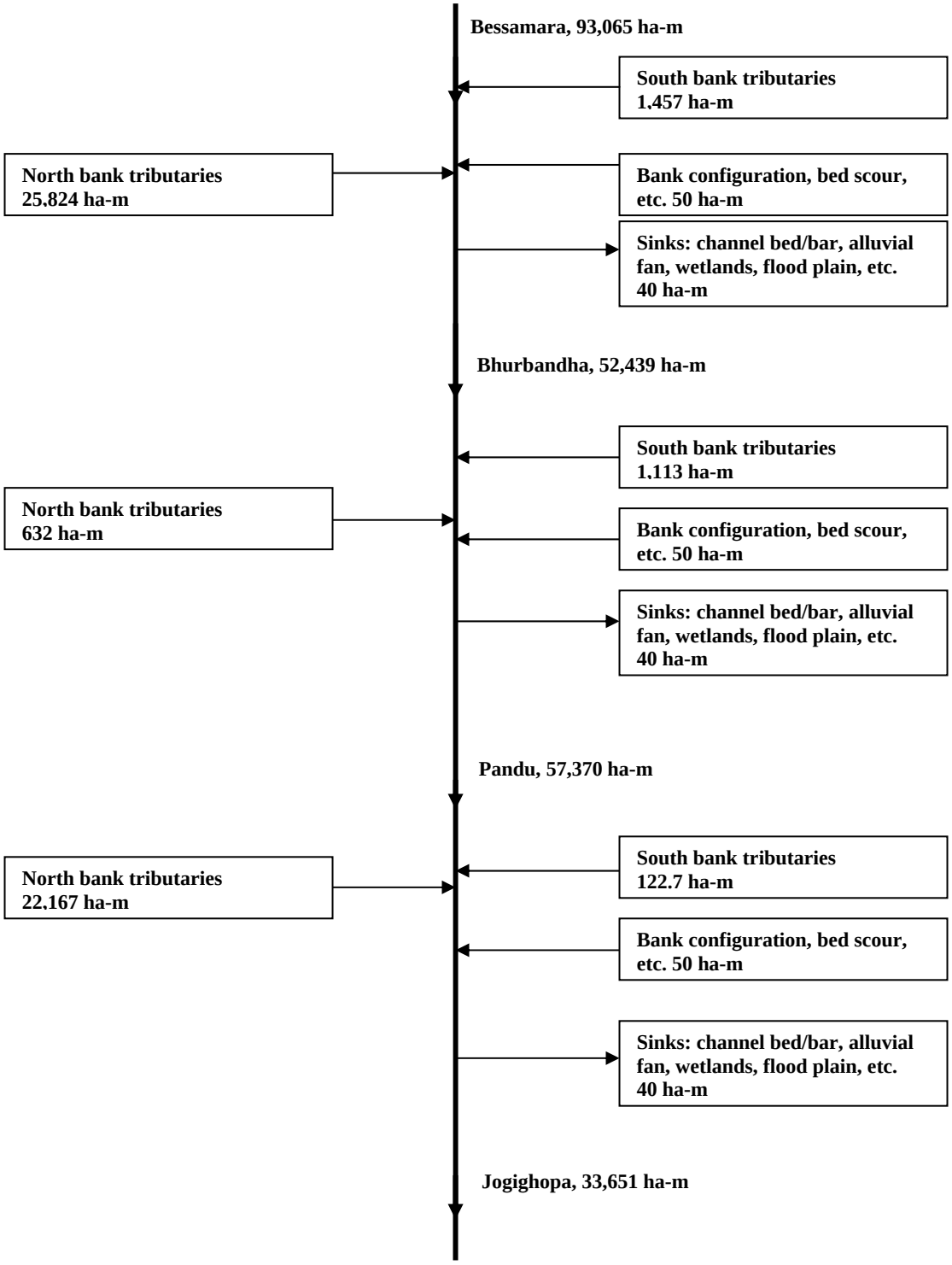
4.2 Gross sediment budgets

The patterns of sediment yield of the Brahmaputra River at different gauging stations and some its major tributaries near their confluence with the main stem is shown in figure 4. The figures indicate that the Brahmaputra carries the highest amount of sediment per unit drainage area among the large rivers of the world, next only to the Yellow River in China. The figures are even higher for some of its major tributaries.

The budgeting is conducted based mainly on sediment yields at selected reaches on the main stem and at confluence points of tributaries. The sediment contributions from such sources as bank failure and bed scour are tentatively estimated based on the limited available data and personal estimates of the second author. Various sediment sources and sinks, such as channel beds and bars, alluvial fans, wetlands, and floodplains, have been similarly quantified. The budgets indicate sediment gains, and hence aggradation, in the Bessamara-Bhurbandha and Pandu-Jogighopa reaches, in the amounts of 67,957 hectare-meters and 46,059 hectare-meters respectively, while there is scour in the Bhurbhanda-Pandu reach of 3,136 hectare-meters (Goswami 1985).

Sediment budgets provide a useful framework for scientific research, policymaking, and decision support. There are three major components of the budget, namely production, transport, and storage or removal of sediments. There are various techniques for estimating the rates for each of these components. One of the most popularly used techniques for estimating erosion rates from watersheds is the universal soil loss equation. However, in the case of the large subwatersheds of the Brahmaputra, the potential of the technique has not yet been adequately tested. It needs to be carefully assessed, along with the requisite improvements in the input data quality, using geoinformatics and other modern tools.

Figure 4. Sediment budget for the Brahmaputra River reaches in Assam



5. Observations

The following observations are offered based on the preceding comprehensive review of the fluvial geomorphology knowledge base of the Brahmaputra, in terms of both the collected data and the available literature:

a. Compared to other large alluvial rivers, the knowledge base on the fluvial geomorphology of the Brahmaputra contains an appreciable quantity of information. However, there are serious gaps in the existence and availability of data required for various fluvial geomorphological assessments. While in certain cases the concern stems from the quality of data or the absence of meaningful analyses, in many cases crucial data are nonexistent.

b. There is no overall framework or approach to inform and organize the data collection and systematization effort. Therefore, critical gaps in data have remained unidentified so far, while in many cases resources have been devoted to the collection of data that have low priority and little applicability from fluvial geomorphology or river management perspectives. In short, the data-building process is not managed.

c. Compared to the data availability on the river, datasets pertaining to catchment characteristics and processes are sparse and of poor quality.

d. The published literature on the fluvial geomorphology of the Brahmaputra River is rather limited, is widely scattered in its distribution, and is devoid of proper cataloging.

e. Most of the relevant information is available in government reports and in engineering dissertations. While a number of government reports (most notably the Brahmaputra basin master plan prepared by the Brahmaputra Board) are classified as confidential, the engineering dissertations on the subject have rarely been published in scientific journals. This combination has created an unfortunate scenario whereby an important fraction of the knowledge base is not easily accessible to the scientific community. Even more importantly, given that most of the information is in these two categories, the lack of peer review has caused serious concerns about the quality and utility of the information.

f. Relatively more research has been conducted on the main stem of the Brahmaputra River than on the tributary rivers.

g. With the exception of the studies utilizing remote sensing data, most of the research efforts rely on data from the same sources: the Central Water Commission, the Brahmaputra Board, and the Water Resources Department of the Government of Assam. Often these data are not authenticated by the agencies.

h. There is significant repetition in the literature. Consequently, in most of the work the value addition to the already existing knowledge base is minimal.

i. There is a preponderance of anecdotal and qualitative work.

j. The number of research efforts pertaining to quantitative techniques that can provide useful empirical data and information on the fluvial processes of the river is quite limited:
    - The knowledge base has an uneven focus. The various dimensions of fluvial geomorphology have not received attention proportional to their significance.
    - There are numerous studies, based on remote sensing data, on the subjects of fluvial planform evolution, bank erosion, and floods. Flood-related studies are the most frequent.
    - Studies at basin or subbasin level requiring extensive field-based observational data inputs or analytical procedures, such as modeling or simulation, are rare.
    - Most studies are area specific or site specifc in their spatial focus. Reach-level analyses are rare. Suprareach-level analyses are nonexistent.
    - Rigorous analytical work in modeling and simulation is lacking.

k. The Brahmaputra is a large alluvial river with a highly variable channel morphology and a high degree of braidedness. The dominant flow regime is multichannel flow over a movable bed, which is acknowledged to be very complex. Data collection and interpretation in such fluvial regimes is a difficult enterprise, as is the task of developing analytical models of fluid and sediment flows. Consequently, there are no reported analytical models that can adequately capture the flow regime of the Brahmaputra. However, pioneering work on empirical modeling has been attempted using the technique of artificial neural networks. This relies on training of neural networks to mimic the behavior of the river systems, based on historical data. This has been an important step towards development of river models with predictive capabilities.

l. While there has been a revolutionary change in the last two decades regarding the availability of technologies for data collection and analysis, there has not been a commensurate improvement in the knowledge base (with the exception of a few studies based on remote sensing data). Current understandings of such vital issues as sediment transport, aggradation and degradation in river reaches, and catchment change processes are all based on old data and therefore seriously compromised.

6. Recommendations

The following recommendations emerge from the foregoing review:

a. The database pertaining to the fluvial geomorphology of the Brahmaputra needs to be improved and updated. In particular, efforts should be launched to address the following critical deficiencies in the database:
    - Sparse coverage of meteorological and land use data in the upper catchment areas

- Absence of ground-truthing of various geospatial data, especially in remote areas
- Absence of systematized data series for catchment change processes
- Complete absence of bedload measurements
- Absence of data on thalweg, bank top, bar top and water surface profiles
- Inadequate data on cross-sections in eroding reaches.

b. The investments in data collection efforts should be decided and informed by the adoption of a systematic approach, so that a coherent set of data objectives can be targeted, and redundancy and wasteful expenditures avoided. Thorne's framework for fluvial geomorphological assessment of large alluvial rivers is recommended as a useful approach.

c. The stringent requirements for access to the significant quantity of existing confidential data need to be reexamined, in light of the fact that a number of well-founded imperatives for confidentiality have become irrational due to technological development, and that poor access to classified data continues to hamper the improvement of our scientific understanding of the river system. It is recommended that:

- Data be declassified where historical rationales for confidentiality do not apply any more
- In cases where access to data needs to be controlled, the information be disaggregated so that nonsensitive but useful information is not lumped with classified information.

d. In general, access to nonclassified information needs to be improved. The Central Water Commission's current initiative on making information available on request is a welcome step forward. However, access could be significantly improved further by increasing the availability of nonclassified information datasets through the websites of the respective agencies.

e. In addition to including crucial data parameters and improving spatial coverage, the quality of the data collected should be improved by making investments in upgrading antiquated measurement techniques. The most critical requirements are for two- and three-dimensional velocity measurements, suspended sediment measurements, and bedload sediment transport measurements.

f. The adequacy of the number of data collection sites (65) on the Brahmaputra system needs to be reassessed with the objective of improving data collection in geomorphologically active reaches.

g. The Central Water Commission has undertaken a commendable initiative on the harmonization of data collection efforts with a view to avoiding duplication and internal inconsistencies between the programs managed by the main responsible agencies. Similar harmonization is required for data interpretation and analysis aspects.

h. From a fluvial geomorphological perspective, project-specific investigations are incomplete and minimally effective without the input and context provided by

catchment-scale analyses. However, no individual river management or water resource project would be able to afford to carry out catchment-scale analyses on the Brahmaputra system. Therefore:

- Catchment-level research needs to be coordinated and conducted at regional level, with central support.
- A coherent research program needs to be designed, with clearly specified objectives in terms of data and understanding, and with an approach comprising a series of well-defined tasks to achieve the specified objectives.
- A successful research initiative would require developing partnerships between government agencies and academic institutions. Given the breadth of disciplines called to contribute to the physical understanding of large systems, a research consortium approach building on the strength of various different institutions is recommended. The Central Water Commission's current support and facilitation of fluvial geomorphology research at some premier institutions could be a starting point for furthering a collaborative approach.
- A well-defined research program, with access to information and relatively modest outlays of funds, would be able to generate practicable knowledge on river management and development for the Brahmaputra system, which in turn would go a long way towards ensuring optimality and sustainability of investments.

7. Epilogue

T. S. Eliot, in *The Dry Salvages*, seems to capture quite concisely the limits of our understanding of rivers:

> I do not know much about gods; but I think that the river
> Is a strong brown god – sullen, untamed and intractable,
> Patient to some degree, at first recognized as a frontier;
> Useful, untrustworthy, as a conveyor of commerce;
> Then only a problem confronting the builder of bridges.
> The problem once solved, the brown god is almost forgotten
> By the dwellers in cities – ever, however, implacable,
> Keeping his seasons and rages, destroyer, reminder
> Of what men choose to forget . . .

The Brahmaputra is a majestic force of nature, running not only across the landscape of the Northeast but also through the daily lives and livelihoods of the millions of people of the region. This whimsical son of Brahma feeds the people, waters their fields, and carries their burdens, and thus in numerous ways sustains them, and yet, annually ferocious, it destroys as well. The river god is powerful and complex, and this is true not just for the Brahmaputra but for the Barak, the Rangit, the Sankoh, the Teesta, and indeed for all the rivers of the Northeast. These rivers are the wealth and the lifelines of the region and of its peoples; they are the gods that give many times and in many ways, and yet to stay on the good side of the gods we need to understand them. Knowledge is

the key to understanding these rivers. The mandate of poverty alleviation and economic development of the region, therefore, translates into an imperative to generate an understanding that would allow a sustainable and productive development of the water wealth of the region.

Bibliography

Note: This bibliography pertains to the fluvial geomorphology practice and its applicability to the Brahmaputra basin. For a detailed and annotated literature review on the Brahmaputra, see appendix A.

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Appendix A. Literature review

[(+) indicates utility and relevance for the subject of this paper]

No.	Title	Author	Year	Document type	Keywords
1	Geoecological study of beels and swamps of Nagaon and Morigaon Districts, Assam	Sarma, P.	1993	Ph.D. thesis Gauhati Univ.	Origin, morphology, spatiotemporal changes, hydrology, water quality, human impact, role in flood moderation
2	A study of geomorphology and flow characteristics of Gabharu River, Assam	Roy, L.	2000	Ph.D. thesis Gauhati Univ.	Fluvial geomorphology and flow characteristics, drainage morphometric analysis, floodplain morphology, flow analysis, flood frequency
3	Sedimentological studies of modern sediments of the Brahmaputra River around Neamatighat (Jorhat), Assam	Borthakur, J.	1995	Ph.D. thesis Gauhati Univ.	Geomorphological study, sedimentary structures, grain size analysis, depositional conditions, clay minerals, geochemistry of sediments
4	Erosion aspects of Brahmaputra River around Maijan and Mathda, Dibrugarh districts, Assam: A geological study (+)	Ahmed, H.	1986	M.Phil. thesis Gauhati Univ.	Geotechnical properties of soil, river flow, silt discharge, hydrometeorological aspects, tectonic movement and effects, antierosion measures, course and channel change
5	Geomorphology of Kopili basin, N.E. India (+)	Saikia, R.	1990	M.Phil. thesis Gauhati Univ.	Geomorphological and erosional aspects of the basin, morphogenetic regions, geoecological conditions
6	Studies on water quality of the River Bharalu in terms of physicochemical as well as bacteriological water quality parameters	Thakuria, A.	1999	M.Phil. thesis Gauhati Univ.	Physicochemical parameters, bacteriological qualities (total coliform, E. coliform), human impact, pollution load
7	A study on degradation of the water quality parameters of Bharalu River at Guwahati	Basak, S.	1993	M.Phil. thesis Gauhati Univ.	Water quality status (physicochemical and bacteriological parameters) pollution impact

No.	Title	Author	Year	Document type	Keywords
8	A study of productivity of Deepar beel with reference to its pollution status	Borooah, D.	1999	M.Phil. thesis Gauhati Univ.	Use of light and dark bottle method of Gaader and Gran
9	Studies on some water quality parameters of Deepar beel of Guwahati area	Gosain, A.K.	1991	M.Phil. thesis Gauhati Univ.	Water quality, main source of pollutants, self-purification, environmental effect
10	Water quality analysis of the Brahmaputra near Guwahati (+)	Saikia, P.K.	1989	M.Phil. thesis Gauhati Univ.	Physicochemical parameters, their seasonal and temporal variations, human impact
11	Flood hazard in the Pagladiya basin: An environmental study	Nath, N.	1989	M.Phil. thesis Gauhati Univ.	Flow characteristics, stage-discharge relationship, sediment discharge, flood frequency analysis, flood hazard
12	Flood damage and its estimation in Pagladiya river basin of Assam	Devi, G.	1998	M.Phil. thesis Gauhati Univ.	Rainfall, daily and annual flow pattern, flood frequency analysis, sediment transport
13	River training and bank protection works of Deogharia area from combined erosion of rivers Brahmaputra, Dikhow and Darika in Sibsagar district (Assam)	Chetia, P.J.	1998	M.E. thesis Gauhati Univ.	Evaluation of existing embankments, river training and bank protection works
14	Flood frequency analysis of the Dhansiri River (Darrang district): A comparative study of different approaches	Deka, M.C.	1987	M.E. thesis Gauhati Univ.	Flood frequency analysis, comparative study using different methods
15	Flood frequency analysis and estimation of flood peaks through empirical formula: A study on a few tributaries of the Brahmaputra and Barak basins	Das, R.	2000	M.E. thesis Gauhati Univ.	Techniques of flood frequency analysis, application potential, evaluation
16	Regimes of flow: Bedload and suspended load of Brahmaputra River at Pandu investigation site (+)	Brahma, J.	1995	M.E. thesis Gauhati Univ.	Suspended bedload estimation, methods and some results
17	Impact of flood on human occupancy in Sadiya region, Assam	Gogoi, B.	1997	M.Phil. thesis Gauhati Univ.	Flood hazard, floodplain occupancy, human impacts
18	Jia Bharali River of Assam: A study in fluvial geomorphology	Bora, A.K.	1990	Ph.D. thesis Gauhati Univ.	Flow and sediment discharge, flood analysis, basin morphology, hazards, human occupancy, human responses

No.	Title	Author	Year	Document type	Keywords
19	Problems of flood, erosion and sedimentation in the Jiadhal river basin, Dhemaji district in Assam: A geoenvironmental study (+)	Hazarika, U.M.	2003	Ph.D. thesis Gauhati Univ.	Pattern of flow, sedimentary environment of bed and banks, channel migration, impact on flood plain, environmental management
20	Some aspects of sedimentology of recent sediments from the River Brahmaputra around Sibsagar, Assam (+)	Bora, M.A.S.	1992	Ph.D. thesis Gauhati Univ.	Assessment of geoenvironment, impact of flood, erosion and sedimentation, formulation of management plan
21	Fluvio-sedimentary environment of the Pagladia and Puthimari rivers: An investigation of their lower catchments in Assam (+)	Duarah, B.P.	1999	Ph.D. thesis Gauhati Univ.	Size analysis, textural parameters, mineral composition, geochemistry of sediments, sedimentary environment
22	Impact of the Brahmaputra flood and erosion hazard on flood plain occupance in the Palasbari-Nagarbera tract of Kamrup district, Assam (+)	Bordoloi, N.	1995	Ph.D. thesis Gauhati Univ.	Channel morphology and dynamics, Flood and erosion hazard, analysis, floodplain occupance and management
23	Some sedimentological and economic aspects of the recent sediments of river in and around Gerukamukh and Dirpaimukh, Lakhimpur district, Assam (+)	Mahanta, S.K.	1993	Ph.D. thesis Gauhati Univ.	Sedimentary features, grain size, mineralogy and geochemistry of sediments, economic aspects of Subansiri sand
24	Fluvio-morphological characteristics of the Mutanga-Nona river basin, Assam	Talukdar, A.K.	1999	M.Phil. thesis Gauhati Univ.	Linear, areal, and relief aspects of basin, geological foundation, soil characteristics, flood, erosion, and deposition
25	A general study of the Kulsi watershed for its management through photo interpretation technique	Bhuyan, R.K.	1987	M.E thesis Gauhati Univ.	Photo interpretation, Kulsi basin, watershed management
26	Flow environment of the Brahmaputra River in Assam: An analysis (+)	Sarma, M.	1987	M.Phil. thesis Gauhati Univ.	Flow pattern, flood frequency analysis, methods, application
27	Landform characteristics of lower Digaru basin, Assam: A morphometric analysis	Baruah, D.	2002	M.Phil. thesis Gauhati Univ.	Relief, drainage density, drainage network, frequency, and pattern, basin morphology, flow characteristics
28	Effect of the Brahmaputra channel migration on flood plain occupance: A case study of the Palasbari-Garaimari tract in South Kamrup (+)	Bordoloi, N.	1986	M.Phil. thesis Gauhati Univ.	Channel migration, floodplain land use, human occupance

No.	Title	Author	Year	Document type	Keywords
29	Flood problem and human response in Mangoldoi subdivision, Assam	Bhattacharjee, N.	2001	M.Phil. thesis Gauhati Univ.	Flood hazard, impact, human response, management
30	A geomorphological study of channel bars in the Puthimari River, Assam	Kalita, H.C.	1993	M.Phil. thesis Gauhati Univ.	Channel bars, geomorphology, formation, changes, impact
31	Geoenvironmental status of wetlands of Guwahati with special reference to Borsola beel	Saharia, D.	1998	M.Phil. thesis Gauhati Univ.	Geomorphological aspects, status, environmental condition, human impact
32	Fluvio-geomorphic characteristics and their impact on the wildlife habitat in the Kaziranga National Park	Mahanta, P.	2001	M.Phil. thesis Gauhati Univ.	Fluviogeomorphic character, erosion hazard, impacts
33	Fluvio-geomorphic characteristics of Pohumara basin, Assam, and strategies for its land use management	Gogoi, M.	2002	Ph.D. thesis Gauhati Univ.	Morphometric characteristics, hydraulic and sediment characteristics, land use pattern, land use management
34	A study of water quality and pollution level of the Bharalu River	Lal, P.C.	1992	Ph.D. thesis Gauhati Univ.	Pollution level, water quality, impact on health and hygiene, management
35	Study of surface water pollution in Greater Guwahati	Kalita, G.N.	1991	Ph.D. thesis Gauhati Univ.	Water quality parameters, sampling, analysis, management
36	A case study on Baltijan microwatershed of Puthimari river basin	Hazarika, S.M.	2003	M.E. thesis Gauhati Univ.	USLE and its use, land erosion, conservation practice, rainfall and runoff factor
37	A comprehensive study of erosion, sedimentation and flooding in the Brahmaputra River in Goalpara district (+)	Al Mahmad, A.H.	2002	M.E. thesis Gauhati Univ.	Rainfall pattern, flow and silt analysis, erosion and sedimentation problems, flood forecasting, flood analysis
38	Analysis and synthesis of flood control measures of Pagladiya River in the Brahmaputra river system	Konwar, N.B.	1980	M.E thesis Gauhati Univ.	Alternative measures: detention reservoir, channelization, levees and dykes, flood insurance, floodplain zoning
39	Computer model for computation of submerged distance and submerged depth of Pagladiya river basin	Deka, P.C.	1994	M.E. thesis Gauhati Univ.	Stage-discharge relationship of Pagladiya River, computation of submerged distance and submerged depth

No.	Title	Author	Year	Document type	Keywords
40	Stochastic model analysis of River Brahmaputra for generation of peak flow sequence and its comparison with frequency analysis (+)	Goswami, P.K.	1996	M.E. thesis Gauhati Univ.	Stochastic model for peak flood analysis, method, comparison with frequency analysis
41	Water balance study for Krishnai watershed	Dutta, P.	1997	M.E. thesis Gauhati Univ.	Method of water balance study, application, discussion
42	Study of water availability for Dudhnoi subbasin (Assam and Meghalaya)	Ahmed, S.	1997	M.E. thesis Gauhati Univ.	Average basin rainfall, rainfall-runoff relationship, flow duration analysis, statistical analysis of runoff estimate
43	A study of infiltration characteristics with soil properties in various land uses of Digaru River subcatchment in Assam	Barman, D.	2001	M.E. thesis Gauhati Univ.	Infiltration characteristics, method of study, land use classes, application potential
44	Hydrogeomorphological studies of Dudhnoi basin	Kumar, A.	2001	M.E. thesis Gauhati Univ.	Linear and areal aspects of Dudhnoi river basin, linear and areal aspects of drainage network, development of geomorphological instant. unit hydrograph (AUTOCAD)
45	Regional flood frequency analysis for the Brahmaputra basin (+)	Hazarika, S.	1991	M.E. thesis Gauhati Univ.	Regional flood frequency study: homogeneity test, confidence band, regression analysis, drainage basin features
46	Flood frequency analysis using annual and partial duration series for the River Subansiri and comparison of the statistical methods (+)	Singha, S.J.	1993	M.E. thesis Gauhati Univ.	Gumbel extreme value, log-Pearson, log-normal, log-Boughton, logging positon formulae: Weibul, Blorn, Gringorten and Cunnane, D-index method
47	A comprehensive study of flood frequency analysis of River Subansiri (computer-aided approach) (+)	Das, S.B.	1998	M.E. thesis Gauhati Univ.	Study of peak flood of different recurrence interval using different methods, D-index method for flood frequency

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48	Flood frequency analysis using annual and partial series for the River Ranganami and comparison of the statistical method (+)	Singha, K.J.	1993	M.E. thesis Gauhati Univ.	Gumbel, log-normal and log-Boughton distribution, plotting position formulae: Weibul, Blorn, Gringorton and Cunnane, D-index method
49	Stochastic analysis of stream flow records of River Pagladiya for generation of peak flow sequence and estimation of monthly flow volume (+)	Ahmed, J.U.	2001	M.E. thesis Gauhati Univ.	Estimation of probable peak discharge and pattern of monthly flow volume by stochastic method
50	A general study of the Kulsi watershed for its management through photo-interpretation technique	Bhuyan, R.K.	1987	M.E. thesis Gauhati Univ.	Photo interpretation, watershed management
51	Flood estimation of Kopili River	Bora, D.	1999	M.E. thesis Gauhati Univ.	Peak flood study by different flood frequency analysis, D-index method and FRG method
52	Flood frequency analysis and stochastic modeling for flood flow of the river of Brahmaputra (+)	Kemprai, B.	2002	M.E. thesis Gauhati Univ.	Determination of peak discharge at different recurrence levels, determination of most suitable method of flood frequency analysis
53	Management of Baladi watershed in North Kamrup	Sarma, A.K.	1987	M.E. thesis Gauhati Univ.	Watershed characteristics, management, methods and use
54	Pattern of sediment transport and sedimentation in the River Burhidihing, Assam	Deka, P.K.	1988	M.E. thesis Gauhati Univ.	Sediment transport, sedimentation, measurement, management
55	Estimation of runoff using remote sensing data: A case study at Dudhnai subbasin	Kalita, J.	1995	M.E. thesis Gauhati Univ.	Remote sensing, method, application in runoff estimation
56	Flood frequency analysis of the tributaries of the River Brahmaputra in Darrang districts	Paharia, B.	2003	M.E. thesis Gauhati Univ.	Flood frequency analysis, methods, application, uses
57	Protection of Dhubri town from erosion of River Brahmaputra	Das, H.K.	2004	M.E. thesis Gauhati Univ.	Erosion hazard, protection measures, effectiveness
58	Comparison of Gumbel's method and log-Pearson type III method of flood frequency analysis for rivers in North East Region (+)	Ahmed, J.A.	1994	M.E. thesis Gauhati Univ.	Comparison of Gumbel's method and log-Pearson type III method for 20 rivers
59	Land use planning and land management of Nonai watershed, Nagoan district, Assam (+)	Hazarika, U.M.	1998	M.E thesis Gauhati Univ.	Land use, land management, watershed plan, Nonai River
60					

No.	Title	Author	Year	Document type	Keywords
61	Flood storage in reservoirs (+)	Das, K.	1993	M.E. thesis Gauhati Univ.	Study of flood storage in selected reservoirs of NE India
62	A study of spurs with special reference to Palasbari-Gumi project (+)	Kalita, B.	1998	M.E thesis Gauhati Univ.	Study of spurs in Gumi Palasbari area, technical details, usefulness
63	Pattern of channel migration of the Brahmaputra River near Palasbari, Assam	Shahid, M.A.	1991	M.Phil. thesis Gauhati Univ.	Channel migration, bank erosion, impact on population and land
64	Photogeomorphological aspects of parts of Ganga and Brahmaputra alluvial plains in India (+)	Raman, V.A.V.	1992	M.Phil. thesis Gauhati Univ.	Photo interpretation, channel morphology, river migration
65	Study of channel bars (chars) in the Brahmaputra River near Guwahati. Project report, sponsored by ASTEC (+)	Goswami, D.C., Deka, H., Barthakur, P.	1994	Project report ASTEC	Sandbar (char) near Guwahati, geomorphology, sediment regime, environmental changes
66	Hydrogeomorphological study of Karbi Anlong district, Assam, using remote sensing techniques (+)	Goswami, I.D.	1994	Ph.D. thesis Gauhati Univ.	Remote sensing application, hydrogeomorphology, groundwater, geological mapping
67	Deepar beel: A geo-environmental study	Deka, S.K.	1990	M.Phil. thesis Gauhati Univ.	Geomorphology, hydrology, sedimentology, water quality, environmental management of Deepar beel
68	Meteorological and geomorphological cause of floods in India with special reference to large drainage basins (Brahmaputra and Ganga). In special issue on flood, Civil Engineering Division Board, Institute of Engineers (India), Kolkata and Bihar State Centre (+)	Mukhopadhyay, S.C.	2000	Research paper Institute of Engineers (India)	Meteorology, geomorphology of Brahmaputra and Ganga river floods, selected aspects
69	Bank erosion at Majuli Island, Assam. In special issue on flood, Civil Engineering Division Board, Institute of Engineers (India), Kolkata and Bihar State Centre (+)	Singh, C.P., Srivastava, S.B.	2000	Research paper Institute of Engineers (India)	Bank erosion, channel changes, mechanism, Majuli Island
70	Master plan of Majuli Island (+)	Brahmaputra Board, Guwahati	2000	Report Brahmaputra Board	Master plan of Majuli Island, protection
71	Report on erosion problem of Majuli Island (+)	Brahmaputra Board, Guwahati	1997	Report Brahmaputra Board	Erosion problem of Majuli

No.	Title	Author	Year	Document type	Keywords
72	A study based on multi temporal satellite data for Majuli Island (+)	Space Application Centre (ISRO), Ahmedabad, and Brahmaputra Board	1996	Report ISRO	Satellite mapping of Majuli Island, bank erosion, channel changes, spatiotemporal scales
73	Development of regional flood frequency analysis using L-moment for gauged catchments of north Bihar region. In souvenir, 17th Water Resources Day, 12 July 2002, p. 8	Kumar, R., Chatterjee, C., Panigrahy, N., Singh, R.D.	2002	Souvenir paper	Regional flood frequency, method, application, L-moment
74	Role of ground water recharge in integrated development of the Brahmaputra valley. In souvenir, 17th Water Resources Day, 12 July 2002, p. 1	Bakshi, A.R., Devi, S.	2002	Souvenir paper	Groundwater recharge, its need for integrated development of the Brahmaputra valley
75	Prospect of water resource development in North East India. In souvenir, 17th Water Resources Day, 12 July 2002, p. 19	Mitra, A.K.	2002	Souvenir paper	Water resource of NE region, Potential for development
76	A case study of discharge analysis of a Brahmaputra tributary: Dhansiri River. In souvenir, 16th Water Resources Day, p. 6	Panigrahy, N., Mani, P., Patowary, B.C.	2001	Souvenir paper	Flow analysis, Dhansiri River, characteristics, flood hazard
77	Role of dam in flood management of River Brahmaputra. In souvenir, 16th Water Resources Day, p. 31	Chakravarty, A.	2001	Souvenir paper	Dams on Brahmaputra River, their role in flood management
78	Bogibeel bridge on River Brahmaputra: Hydraulic model studies. In souvenir, 20th Water Resources Day, p. 19 (+)	Singh, R.K.	2005	Souvenir paper	Hydraulic model, main features, Bogibeel bridge site
79	Restoration of breaches of north bank flood protection dyke of River Brahmaputra at Karenghat in connection with Bogibeel bridge project. In souvenir, 20th Water Resources Day, p. 28 (+)	Singh, M., Choudhary, J.K.	2005	Souvenir paper	Flood protection dykes, breach restoration at Kareng Chapari
80	Hydrometeorology of Brahmaputra basin: Recurrence of high flood in the valley and resultant economic loss. In souvenir, 20th Water Resources Day, p. 48	Dutta, B.	2005	Souvenir paper	Flood occurrence in Assam, intensity, causes and effects
81	Estimation of design flood using GIUH approach: A case study of Kulsi basin. In souvenir, 18th Water Resources Day, 2003, p. 25 (+)	Panigrahy, N., Patwary, B.C., Bhatia, K.K.S.	2003	Souvenir paper	Features of GIUH approach, application in Kulsi river basin
82	Flood in Assam and its mitigation. In souvenir, XVII National Convention of Civil Engineers, p. 23	Mitra, A.K.	2002	Souvenir paper NCCE	Flood hazard in Assam, causes and consequences, mitigation

No.	Title	Author	Year	Document type	Keywords
83	Flood control measures in the Brahmaputra valley: Their effectiveness and necessity. In souvenir, 58th Annual Convention of Institution of Engineers, p. 50	Gohain, H., Jain, P.C.	1998	Souvenir paper IE	Flood control measures, their need and usefulness, limitations
84	Introspection on vistas of outlook in the domain of flood in Assam. Journal of Institution of Engineers (India), 75:124	Das, P.K.	1994	Souvenir paper IE	Perspectives on floods, causative factors, management
85	Control of flood and development of navigation channel in the rivers of Assam. In Technical Volume, Institution of Engineers (India), p. 77	Goswami, B.	1997	Research paper IE	Flood management, navigation in Assam, need for development
86	The River Brahmaputra (NW-II), its channel condition and navigational effect. In Technical Volume, Institution of Engineers (India), p. 107	Das, R.M.	1997	Research paper IE	Brahmaputra as NW-II channel, impact of navigation
87	Geomorphological dimension of the Kapili basin. Journal of Society and Environment, 2:12 (+)	Saikia, R.	1999	Journal	Geomorphology of Kopili basin, hydrology, geoenvironment
88	Puthimari watershed: Parts of Kamrup and Darang district, Assam. Project report on Integrated Mission for Sustainable Development (IMSD), sponsored by Department of Space, Government of India (+)	ARSAC (ASTEC)	1997	Research paper ASTEC	Sustainable development, integrated watershed plan, use of satellite remote sensing/GIS
89	Phases of sedimentation as recorded in the fluvial deposits of Puthimari River, Assam. Journal of Geoscience, p. 49 (+)	Duarah, B.P., Das, P.K., Goswami, D.C.	1997	Journal	Fluvial deposits, characteristics, phases of sedimentation.
90	River metamorphosis through space and time: An account of Burhidihing river basin and its adjoining areas, Assam, India. Journal of Geoscience, p. 56 (+)	Phukan, P., Patgiri, A.K.	1996	Journal	Channel migration, changing morphology, alluvial regime
91	Pebble analysis of the Pagladiya river bed in its upper reach at Khairani, Assam. Proc. volume, Development of Geological Research in Northeast India, p. 131 (+)	Duarah, B.P., Goswami, D.C., Das, P.K.	1996	Research paper	Coarse bedloads, sampling and analysis, characteristic flow and alluvial regimes, stratigraphy
92	Geomorphic control on morphometric parameters of drainage basins: A case study of some constituent watersheds of lower Subansiri basin, North East India. Proc. volume, Development of Geological Research in Northeast India, p. 405 (+)	Goswami, U., Sarma, J.N., Patgiri, A.D.	1996	Research paper	Basin morphometry, geologic and geomorphic controls, salient features of watersheds
93	Lithotectonic control on morphometric parameters of the Dikhow river basin, Assam. Proc. volume, Development of Geological Research in Northeast India, p. 425 (+)	Amin, N., Sarma, J.N.	1996	Seminar paper	Basin morphometry, impact of lithotectonics, channel changes, geoenvironment

No.	Title	Author	Year	Document type	Keywords
94	Morphometric analysis of Kalyani river basin, Assam. Proc. volume, Development of Geological Research in Northeast India, p. 437	Sarma, I., Patgiri, A.D.	1996	Seminar paper	Analysis of basin morphometry, geological control, hydrology
95	Wetlands of Assam. Project report prepared by ARSAC, Assam Science and Technology Council, sponsored by Department of Space (+)	ARSAC (ASTEC)	1997	Seminar paper	Classification, identification, satellite mapping of wetlands
96	Bank erosion at Majuli Island: A study based on multitemporal satellite data. Project report (+)	Brahmaputra Board.	1997	Seminar paper	Erosion problem in Majuli, main features, strategy, control
97	Watershed polarization of Dhansiri catchment, Brahmaputra basin, using remote sensing technique. Report prepared by AISLUS and SAC (Department of Space, Government of India) (+)	All India Soil and Land Use Survey, Delhi, and Space Application (ISRO), Ahmedabad	1995	Project report	Watershed prioritization, use of satellite data, integrated plan
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99	Basin and sub-basin inventory of water pollution: The Brahmaputra basin (+)	Central Pollution Control Board, New Delhi	2000	Project report CPCB	Pollution status of Brahmaputra basin, salient features, database
100	Fluvial processes in the floodplains of Subansiri River and their impacts on arable land	Das, A.K.	2000	Project report	Fluvial processes, hazard profile, impact on arable land
101	Geomorphological study of the Dikhow river basin, India (+)	Amin, N.	1995	Report	Geomorphological setting, basin hydrology, channel change
102	Fluvial environment and mechanism of flood plain formation in the Dhansiri river basin, Assam (+)	Sarma, R.	2001	Ph.D. thesis JNU	Mechanism of floodplain formation, alluvial regime
103	Geomorphology of Kamrup districts: A morphometric and quantitative analysis	Barman, R.	1986	Ph.D. thesis Dibrugarh Univ.	Morphometric analysis of landforms, fluvial processes
104	District report in hydrogeomorphological studies, Nagoan district	ARSAC, ASTEC	1990	Ph.D. thesis Gauhati Univ.	Groundwater targeting, mapping using satellite data
105	Physico-chemical properties of the Deepar beel water. Journal of the Assam Scientific Society, 31(3):15 (+)	Bhattacharyya, K.G., Kakati, G.N.	1990	Ph.D. thesis Gauhati Univ.	Environmental monitoring of wetland, pollution status
106	Environmental status of beels in Assam. Compendium of workshop on development of beel fisheries in Assam, Assam Agricultural University, Khanapara, p. 114 (+)	Bhuyan, M.C.	1987	Project report	Present status, use, degradation of Deepar beel, management

No.	Title	Author	Year	Document type	Keywords
107	Ecology and management of beels in Assam: A case study of Dhir beel. Compendium of workshop on development of beel fisheries in Assam, Assam Agricultural University, Khanapara, p. 16 (+)	Jhingram, A.G. Pathak, V.	1987	Research paper	Ecological status and present use of wetlands, Dhir beel
108	Aspects of geoecology of wetlands (beels) in Nagaon and Morigaon districts of Assam. Paper presented in Assam Science Society seminar at Gauhati University	Sarma, P.	1992	Seminar paper	Wetlands of Nagaon and Morigaon districts, status
109	Pattern and formation processes of wetlands in Nagaon districts, Assam. Paper presented in 14th Conference of Indian Institute of Geomorphology, organized by Northeast Hill University, Shillong	Sarma, P.	1992	Seminar paper	Morphology and formation of wetlands, geomorphic processes
110	Origin, formation and transformation of wetlands in Nagaon and Morigaon districts, Assam. Paper presented in seminar organized by Department of Environmental Science, Gauhati University	Sarma, P.	1993	Seminar paper	Origin, transformation, human impact on wetlands, their development and management
111	Studies on the ecology of an ox-bow lake in the context of development of beels in Assam. Compendium of workshop on development of beel fisheries in Assam, Assam Agricultural University, p. 70 (+)	Yadav, Y.S.	1987	Seminar paper	Ecology of wetland, present use and prospect for development
112	Proceedings of the seminar on fluvial processes and geomorphology of the Brahmaputra basin. Miscellaneous publication 32, Geological Survey of India, Calcutta (+)	Geological Survey of India	1977	Seminar paper	Compendium of papers related to fluvial processes and geomorphology of Brahmaputra
113	Proceedings of the seminar on fluvial processes and geomorphology of the Brahmaputra basin. Miscellaneous publication 46, GSI (+)	Geological Survey of India	1981	Seminar paper	Compendium of papers, fluvial processes of Brahmaputra
114	Geomorphology of the Brahmaputra basin: Its flood problems and their possible remedial measures. Miscellaneous publication 46, GSI, p. 21 (+)	Barman, G.	1981	Proceedings volume	Geomorphology, flood problem, remedial strategies
115	Changes in river courses in certain parts of the Brahmaputra. Miscellaneous publication 46, GSI, p. 85 (+)	Chansarkar, R.A.	1981	Proceedings volume	Channel changes, bank migration, geological aspects
116	The course of the River Brahmaputra. Souvenir, Assam Science Society, p. 17	Kedia, D.	1978	Report	General account of the river profile, earlier observations

No.	Title	Author	Year	Document type	Keywords
117	Hydrological and sedimentological studies in parts of Dikhow-Disang sub-basin of Sibsagar district, Assam, with special reference to groundwater resource evaluation (+)	Patgiri, A.D.	1989	Report	Groundwater, sedimentary environment of Dikhow-Disang river basins, some estimates
118	Aerial geological controls on the Brahmaputra fluvial processes. Miscellaneous publication 46, GSI, p. 73 (+)	Roy Choudhury, M.K.	1981	Seminar paper	Photo interpretation, fluvial landforms of Brahmaputra River
119	Morphometric characteristics of some drainage of Upper Assam, India. Proceedings of seminar on recent advances on the study of the Cainozoic geology of north eastern parts of India, Dibrugarh University	Sarma, J.N.	1987	Ph.D. thesis Dibrugarh Univ.	Morphometry of basins, characteristics and controls
120	A geomorphological study of the Dikhow river basin, India (+)	Amin, N.	1995	Report	Geomorphological setting of Dikhow River, processes, forms
121	1998 flood in India: An analysis. Report prepared by the Brahmaputra Board, January 1999	Brahmaputra Board	1999	Seminar paper	Flood report of 1998, main features, analysis of hydrological data
122	Hydrogeomorphological mapping of Assam (district wise). Project report, ARSAC, ASTEC, Guwahati (+)	ARSAC, ASTEC	1990	Ph.D. thesis Dibrugarh Univ.	Groundwater mapping using remote sensing and ground data
123	Bankline migration of Brahmaputra River at Palasbari, Assam, using satellite data. Project report, ARSAC, ASTEC, Guwahati (+)	ARSAC, ASTEC	1992	Report	Mapping bankline migration using satellite data, Palasbari
124	Drainage congested area mapping in the Pagladiya river basin. Project report, sponsored by Brahmaputra Board (+)	ARSAC, ASTEC	1996	Report	Satellite survey of drainage congested areas, Pagladiya River
125	Drainage and floods of Assam. In A.K. Bhagawati, A.K. Bora, and B.C. Kar, eds., Geography of Assam, Rajesh Publications, New Delhi, p. 36	Bora, A.K.	2001	Project report	General account of drainage and flood scenario of Assam
126	Flood problem in Assam and its permanent solution. Inaugural address in symposium on flood problem in Assam, Assam Agricultural University	Bora, P.C.	1977	Project report	Perspective on the flood problem, its possible solution
127	Comprehensive plan for Brahmaputra basin, volumes I, II, and III (+)	Brahmaputra Flood Control Commission	1979	Project report	Comprehensive Brahmaputra basin plan
128	Master plan report for all the tributaries of River Brahmaputra and Barak basin, volumes I and II (+)	Brahmaputra Board.	1979	Research paper	Comprehensive plan for tributary rivers of Brahmaputra

No.	Title	Author	Year	Document type	Keywords
129	Barpeta-Kamrup region: An analysis of drainage density and landform. The North Eastern Geographer, 16(1&2):69	Barman, R.	1984	Seminar paper	Analysis of drainage network and landforms of part of Assam
130	Morphometric analysis of average slope in the undivided Kamrup district region of Brahmaputra valley, Assam. The North Eastern Geographer, 21	Barman, R.	1989	Report	Slope morphometry and landform analysis in Kamrup district
131	Drainage and flood in Upper Assam. Proceedings of 21st International Geographical Congress, India, p. 59	Borthakur, M.	1968	Report	Drainage system, flood scenario causes and effects, management
132	Master plan of Brahmaputra basin (+)	Brahmaputra Board	1986	Report	Master plan of the Brahmaputra
133	Master plan of Pagladiya dam project. Brahmaputra Board, Ministry of Water Resources, Government of India (+)	Brahmaputra Board	1988	Report	Master plan of Pagladiya dam project
134	A study of hydrological behavior of the Gabharu River, Assam. Golden Jubilee volume, Gauhati University Journal of Science, p. 19 (+)	Bora, A.K., Roy, L.	1998	Seminar paper	Hydrology and basin environment, Gabharu River, fluvial processes
135	Comprehensive plan for Brahmaputra River. Volume I, p. 243 (+)	Brahmaputra Flood Control Commission	1977	Report	Comprehensive plan of Brahmaputra River, volume II
136	Comprehensive master plan of Brahmaputra, volumes I and II (+)	Brahmaputra Flood Control Commission	1960	Report	Comprehensive master plan for Brahmaputra, volumes I and II
137	The Pagladiya basin: Geomorphology, geology and fluvial processes. Miscellaneous publication 82, Contribution of Geomorphology and Geohydrology of Brahmaputra Valley, GSI, Delhi, p. 78 (+)	Chakrabarti, C.	1977	Research paper	Basin geology, geomorphology, fluvial processes, Pagladiya River
138	Channelisation of River Brahmaputra from Kharmuja to Belikuchi. Prepared under Goalpara E&D Division of Flood Control Department, Government of Assam	Flood Control Department, Government of Assam	1977	Report	Channelization, procedure and impact, part of Brahmaputra
139	Selection of proper statistical distribution for computation of design flood by frequency analysis: A study based on some north bank tributaries of River Brahmaputra. Proceedings of 6th National Symposium on Hydrology with special reference to the NE Region, Shillong, April 10–12, p. 125 (+)	Dutta, B.	1994	Report	Flood frequency analysis using statistical technique, case study

No.	Title	Author	Year	Document type	Keywords
140	The Brahmaputra drainage system. Journal of Northeast India Geographical Society, 1&2:20 (+)	Das, H.P.	1969	Journal paper	Description of Brahmaputra Drainage system, physiography
141	Clay minerals from Brahmaputra river sediments around Sibsagar districts, Assam. Bulletin of Pure and Applied Science, 11F(1&2):1 (+)	Das, P.K., Bora, M.A.S.	1992	Journal paper	Clay minerals in alluvial sediments, analysis, discussion
142	Heavy mineral from the modern sediments of Brahmaputra River around greater Guwahati, Kamrup districts, Assam. Bulletin of Pure and Applied Science, 14F(1&2):63 (+)	Das, P.K., Gogoi, B.K.	1992	Journal paper	Heavy minerals in recent sediments, Brahmaputra floodplain near Guwahati
143	Lithofacies and sedimentary structures in the point bar of Pagladiya River near Nalbari, Assam. Publ. Center for Advanced Study in Geology, Punjab University, Chandigarh, 5:39	Das, P.K., Duarah, B.P.	1996	Seminar paper	Sedimentary environment of point bars, lithofacies, structures
144	Heavy mineral from the modern sediments of the River Brahmaputra in and around Dikhowmukh, Sibsagar district, Assam. Gauhati University Journal of Science, 30A:111	Das, P.K., Bora, M.A.S.	1990	Journal paper	Heavy minerals in modern sediments of Brahmaputra near Dikhowmukh, Sibsagar, Assam
145	Assam: Her flood and hydrology. Proceedings of 21st International Geographical Congress, India, p. 58	Dutta-Choudhuri, A.N., Das, J.	1968	Research paper	Floods in Assam: causes and impact, hydrological aspects
146	Flood hazards of the Jiadhal River in Assam: A case study of the Samarjan area. Geographical Horizon 4, G.U.	Fluvial geomorphology P.G. students group	1994	Journal paper	Flood hazard in Jiadhal basin, field observations, report
147	Contribution of geomorphology and geohydrology of the Brahmaputra valley. Miscellaneous publication 30, GSI, p. 105 (+)	Geological Survey of India	1977	Research paper	Geology, geomorphology, groundwater-related aspects
148	The Burhi Dihing valley and its adjoining areas: A study in historical geomorphology. North Eastern Geographer, 23(1&2):33	Gogoi. B., Barman, R.	1991	Seminar paper	Paleogeomorphological aspects of Burhi Dihing valley
149	Regional flood frequency analysis of Brahmaputra basin in North East India. Journal of Inst. of Engineers (India), 52(7) (+)	Goswami, A.C.	1972	Journal paper	Regional flood frequency analysis, Brahmaputra basin
150	Flood frequency studies and estimation of flood peaks in parts of Brahmaputra basin through empirical formula (+)	Hazarika, J.	1998	Report	Flood analysis using empirical techniques, parts of Brahmaputra basin

No.	Title	Author	Year	Document type	Keywords
151	The Brahmaputra: Its fluvial processes. Souvenir of mid-term symposium on harnessing the Brahmaputra River, Assam Science Society, Guwahati, p. 24	Goswami, D.N.D.	1978	Research paper	Fluvial processes, geological setting of Brahmaputra River
152	Remote sensing for geomorphological, lithological and structural mapping in parts of Brahmaputra valley, Assam. Proceedings of national symposium on remote sensing application with special reference to North Eastern Region, Guwahati, p. 108 (+)	Kumar, V.	1993	Research paper	Geomorphological and structural mapping using satellite data in Brahmaputra basin
153	Flood frequency analysis of Gabharu River in Assam. North Eastern Geographer, 25(1&2):49	Roy, L., Bora, A.K.	1994	Journal paper	Flood frequency analysis, Gabharu River
154	Master plan report of Dudhnai-Krishnai catchment, volume 1. Brahmaputra Board (+)	Brahmaputra Board	1992	Report	Master plan of Dudhnoi-Krishnai basin
155	A preliminary geological report on the selection of dam across the Subansiri River, Subansiri Frontier Division. NEFA, GSI report	Mitra, A.	1955	Research paper	Geotechnical aspects of siting the Subansiri dam
156	Morphological studies of River Brahmaputra. WAPCOS, New Delhi, sponsored by NEC, Government of India, Shillong (+)	WAPCOS, New Delhi	1993	Report	Morphological studies of Brahmaputra River, wide coverage
157	Hydrogeomorphological studies of Dudhnai sub-division (Assam and Meghalaya). NIH report, Es-(AR) 182	NIH	1980	Report	Hydrogeomorphological study, Dudhnai area, Assam/Meghalaya
158	ENVIS newsletter: (i) Flood problem in Assam and its application of space technology, (ii) Districtwise flood inundated area statistics for Assam state, volume 2(3) (+)	ENVIS	2003	Report	Flood mapping using satellite remote sensing techniques
159	Changes in morphology of Brahmaputra River along the Kaziranga National Park: An analysis of multiyear remote sensing data. In Management of sediment control, Central Board of Irrigation and Power, New Delhi, p. 443 (+)	Panigrahy, S., Parihar, J.S.	1995	Report	Morphological study of the Brahmaputra near Kaziranga National Park, satellite based
160	The Pagladiya basin: Geohydrology. Miscellaneous publication 32, Contributions of Geomorphology and Geohydrology of Brahmaputra Valley, Geological Survey of India (+)	Pawde, M.B.	1977	Report	Geohydrology of Pagladiya basin, its geomorphology

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161	A study on palaeo channels from satellite imagery in parts of Upper Assam. Proceedings of national symposium on remote sensing application with special emphasis on N.E. Region, p. 74	Sarma, J.N.	1993	Research paper	Satellite data-based study of palaeo channels in upper Assam
162	The Brahmaputra: A study of Pauranic geography. Journal of North East India Geographical Society, III/IV(1&2):32	Singh, I.D.	1971	Journal paper	Ancient ideas on Brahmaputra River, Pauranic views
163	Some aspects of geomorphology of Kapili basin. Abstract volume, North East India Geographical Society	Saikia, R., Barthakur, M.	1976	Seminar paper	Geomorphological aspects of Kopili basin
164	Fluvial processes and geomorphology of Brahmaputra plain. Geographical Review of India, 36(1):38	Taher, M.	1974	Journal paper	Fluvial activities and landforms of Brahmaputra basin
165	Fluvial processes of the south bank tributaries of Brahmaputra. Abstract volume, North East India Geographical Society	Taher, M.	1976	Journal paper	Fluvial characteristics of south bank tributaries of Brahmaputra
166	Drainage basin study of the Burhi-Dihing River, Assam (+)	Sarma, J.N.	1980	Ph.D. thesis Gauhati Univ.	Geomorphology of Burhi-Dihing river basin
167	On some geotechnical aspects of Subansiri River dam project, Arunachal Pradesh. Miscellaneous publication 43, Geological Survey of India, p. 34 (+)	Srivastava, D.	1983	Ph.D. thesis Dibrugarh Univ.	Geotechnical aspects of Subansiri dam project site
168	On the erosional aspects of Brahmaputra River at Majuli and Mathola, Dibrugarh district, Assam. Quarterly Journal of Geol. Min. Met. Soc., India, 55(1):31 (+)	Ahmed, H., Maswood, M., Hazarika I.M.	1970	Journal paper	Erosion activities in Majuli island and Mathola
169	The Brahmaputra: A myth, a gift and a source of sorrow – Its physiographical interpretation. Souvenir, Assam Science Society, p. 6	Barthakur, M.	1978	Report	Physiography, water resources, and flood hazard of Brahmaputra River
170	The Brahmaputra and the valley of its blessing. Souvenir, Assam Science Society, p. 28	Dutta-Choudhury, A.N.	1978	Research paper	General description of Brahmaputra River and its basin
171	Controlling floods in the Brahmaputra River. Souvenir, 40th Res. Sess., Central Board of Irrigation And Power, India, p. 114	Goswami, A.C.	1970	Seminar paper	Flood management strategy for the Brahmaputra River
172	The Brahmaputra: Its fluvial processes. Souvenir, Assam Science Society, Guwahati, p. 24	Goswami, D.N.D.	1978	Seminar paper	Fluvial processes of the Brahmaputra River
173	The source of the River Brahmaputra. Souvenir, Assam Science Society, p. 17	Kedia, D.	1978	Seminar paper	Discussion about the source of the Brahmaputra River

No.	Title	Author	Year	Document type	Keywords
174	A review of Dibru flood protection works. Report of Flood Control and Irrigation Department, Government of Assam (+)	Kumra, P.N.	1964	Report	A profile of the flood protection works near Dibrugarh
175	Flood control measures in Assam. Souvenir, 40th Res. Sess., Central Board of Irrigation and Power, India, p. 109 (+)	Rashid, A.	1970	Report	Flood control measures in Assam
176	Stream power, bedform, and grain-size relationships in rivers: A case study from the Brahmaputra River, Assam. Journal of Assam Science Society, 32:32 (+)	Goswami, D.C.	1989	Journal paper	Stream power, bedform, and grain-size relationships in the Brahmaputra River, Assam
177	Braiding of Brahmaputra river channel in Assam: A fluvio-geomorphic enquiry. Journal of North East India Geographical Society, 23(1&2):52 (+)	Goswami, D.C.	1991	Journal paper	Mechanism of braiding, causative factors, morphology, Brahmaputra as classic example
178	Alluvial morphology of channel bars: A case study from the Brahmaputra River, Assam. Golden Jubilee volume, Gauhati University Journal of Science, p. 123 (+)	Goswami, D.C., Deka, H., Barthakur, P.	1998	Journal paper	Alluvial morphology of bars, their formation and change, case study on bar near Gauhati
179	Pattern of sediment yield from river basins of the Brahmaputra system, North East India. The North Eastern Geographer, 17(12):1 (+)	Goswami, D.C.	1985	Journal paper	Sediment yield estimates from rivers of Brahmaputra basin, methods of estimation
180	Input data quality as a major determinant of hydrologic model performance: Some observations from the Brahmaputra River, Assam. Proceedings of national workshop on simulation and computer modelling to control the Brahmaputra River. Inst. of Advanced Studies in Science and Technology, p. 9 (+)	Goswami, D.C.	1990	Research paper	Errors in flow and sediment discharge measurement, impact on estimates of channel storage
181	Floods and their impact on agriculture of Assam. In P.C. Goswami, ed., Agriculture in Assam, p. 191 (+)	Goswami, D.C.	1990	Journal paper	Flood hazard in Assam, impact on agriculture, possible solutions
182	Rainfall regime of Northeast India: A hydrometeorological study with special emphasis on the Brahmaputra basin (+)	Das, P.J.	2004	Ph.D. thesis Gauhati Univ.	Variability and distribution of rainfall in NE region, impact on flood, climate change
183	Problems of flood, erosion and sedimentation in the Jiadhal river basin, Dhemaji district, Assam: A geoenvironmental study (+)	Hazarika, U.M.	2003	Ph.D. thesis Gauhati Univ.	Flood, erosion and sedimentation problems in the Jiadhal basin, present status, future prospects
184	Basin environment and flow regime of the Barak River, Assam (+)	Bhattacharya, D.	2005	Ph.D. thesis Gauhati Univ.	Geoenvironment of basin and flow pattern of Barak River

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185	Fluvial environment and mechanism of formation of floodplain in the Jia Dhansiri river basin, Assam (+)	Sarma, R.	2001	Ph.D. thesis Gauhati Univ.	Mechanism of floodplain formation, fluvial activities, morphosedimentary changes
186	Hydrological impact of earthquakes on the Brahmaputra River regime, Assam: A study in exploring some evidences. Proceedings of 18th National Convention of Civil Engineers, 9–10 November 2002, Inst. of Engg. (India), Guwahati, p. 40 (+)	Goswami, D.C., Das, P.J.	2002	Seminar paper	Earthquakes and their impact on the Brahmaputra River regime
187	Perspectives on hydrology, sediment yield, flood hazard and water resources potential of the Brahmaputra River, Assam. Proceedings of seminar, Brahmaputra: Problems and prospects, Guwahati, 29 January 1997, p. 119 (+)	Goswami, D.C.	2003	Seminar paper	Hydrology, sediment transport, flood hazard and water resources of the Brahmaputra, review and discussion
188	ANN model development for bank-line migration of River Brahmaputra using remote sensing data. Journal of Hydraulic Engineering, Indian Society for Hydraulics, 10(1) (+)	Sharma, N., Pandey, A.D., Venkatesh, K.	2004	Journal paper	ANN model, river behavior, bankline migration
189	ANN based spatio-temporal morphological model of the River Brahmaputra (+)	Sankhua, R.	2005	Ph.D. thesis IIT Roorkee	ANN model, morphology
190	Brahmaputra River channel processes and sedimentation. Sedimentary Geology, 3 (+)	Coleman, J.M.	1969	Journal paper	Channel processes, sediment transport, sedimentary geology
191	Fluvial geomorphology. In V.P. Singh, N. Sharma, and C.S.P. Ojha, eds., The Brahmaputra Basin Water Resources, Kluwer Academic Publishers (+)	Bora, A.K.	2004	Research paper	Soils, channel processes, flood geomorphology
192	Hydrogeology. In V.P. Singh, N. Sharma, and C.S.P. Ojha, eds., The Brahmaputra Basin Water Resources, Kluwer Academic Publishers (+)	Purkait, B.	2004	Research paper	Drainage, river morphology, geology, aquifers
193	Hydrology. In V.P. Singh, N. Sharma, and C.S.P. Ojha, eds., The Brahmaputra Basin Water Resources, Kluwer Academic Publishers	Datta, B., Singh, V.P.	2004	Research paper	Basin climate, flooding, sediment loads, bank erosion
194	Channel processes. In V.P. Singh, N. Sharma, and C.S.P. Ojha, eds., The Brahmaputra Basin Water Resources, Kluwer Academic Publishers (+)	Palaniappan, A.B.	2004	Research paper	River braiding, bank erosion, aggradation/degradation, effects of seismicity, modeling

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195	Spatio-temporal morphological features. In V.P. Singh, N. Sharma, and C.S.P. Ojha, eds., The Brahmaputra Basin Water Resources, Kluwer Academic Publishers	Sharma, N., Chakrabarty, R., Ojha, C.S.P.	2004	Research paper	Morphological features, spatiotemporal analysis, remote sensing
196	Mathematical modelling and braid indicators. In V.P. Singh, N. Sharma, and C.S.P. Ojha, eds., The Brahmaputra Basin Water Resources, Kluwer Academic Publishers (+)	Sharma, N.	2004	Research paper	Braided channels, simulation model
197	Water quality, mineral transport, and sediment biogeochemistry. In V.P. Singh, N. Sharma, and C.S.P. Ojha, eds., The Brahmaputra Basin Water Resources, Kluwer Academic Publishers (+)	Mahanta, C., Subramanian, V.	2004	Research paper	Water and sediment biogeochemistry, sediment and chemical erosion
198	ANN based spatio-temporal studies for a typical reach of the Brahmaputra. WRTDC, IIT Roorkee	Patil, T.S.	2001	M.E. thesis IIT Roorkee	River erosion, reach analysis, ANN modeling
199	A study of river morphological analysis of Brahmaputra River from Dibrugarh to Majuli Island. WRTDC, IIT Roorkee (+)	Gupta, U.P.	2000	M.E. thesis IIT Roorkee	Morphological change, reach analysis, remote sensing
200	Flood plain modeling of River Brahmaputra, Assam, India. Department of Water Resources Development and Management, IIT Roorkee (+)	Dwivedi, A.	2005	M.Tech. thesis IIT Roorkee	Floodplain modeling
201	Modelling of Brahmaputra River cross-sections using ANN technique. Water and Energy International, 59(3) (+)	Sharma N., Pandey A.D., Venkatesh, K.	2002	Journal paper	ANN modeling, bankline behavior
202	Morphological analysis of Brahmaputra River using satellite data and GIS. WRTDC, IIT Roorkee (+)	Singh, L.	2002	M.Tech. thesis IIT Roorkee	Remote sensing, flood analysis, bankline migration
203	Study of effects of river training works on riverine geomorphology at some selected places on the Brahmaputra. Department of Civil Engineering, University of Roorkee (+)	Bhagawati, D.	1991	M.E. thesis Roorkee Univ.	River training, sediment transport, reach analysis
204	Spatio-temporal morphological analysis using satellite data for a reach of the Brahmaputra. WRTDC, IIT Roorkee (+)	Singh, M.K.	2002	M.Tech. thesis IIT Roorkee	Remote sensing, morphological change

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205	Remote sensing aided idealization of space-time variant behavior of channel geometry of River Brahmaputra. Final report for Ministry of Water Resources, Department of Water Resources Development and Management, IIT Roorkee (+)	Dept of Water Resources Development and Management, IIT Roorkee	2005	Research report MoWR	Channel geometry evolution. Modeling, remote sensing, ANN simulation